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QUALIFICATION OF THE GEMINI SE-7 ENGINE AS THE SATURN S-IVB STAGE ULLAGE CONTROL THRUSTER

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ABSTRACT

The Gemini SE-7 Engine was qualification tested for use as the ullage motor for the Saturn S-IVB stage. The engine was subjected to hot firing tests and vibration/shock tests. All program objectives were met and the engine was deemed qualified for use in the S-IVB stage Auxiliary Propulsion System.

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PROPULSION AND VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Concluded)

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SUMMARY

A test program was conducted to qualify the Rocketdyne, Gemini SE-7 Engine for use as the ullage control thruster for the Saturn S-IVB stage. The program was performed in two phases: a hot firing test series, designed to qualify the engine for the S-IVB Auxilliary Propulsion System (APS) duty cycle and environment; and a vibration/shock test series to sybject the engine to structural loading estimates of the stage input to the APS module.

The hot firings demonstrated the engine capability of meeting the specified requirements for S-IVB ullage control. Vibration analysis indicated the thrust chamber assembly was weak in the areas of attachment to the APS module. Modifications to the attach points were designed, fabricated, tested successfully, and incorporated into the flight version of the engine. All program objectives were met and the engine was deemed qualified for use in the S-IVB stage application.

INTRODUCTION

On March 24, 1965, the hot firing of a Rocketdyne SE-7 engine initiated a program to qualify this type thrustor as the ullage control engine on the S-IVB stage. The SE-7 engine was designated for this application by NASA Headquarters on March 30, 1964. The decision was based upon a recommendation made by the OMSF Storable Fuel and Engine Task Force in December, 1963. This group surveyed the field of existing small, storable propellant engines and determined the SE-7 to be best suited from the standpoint of propellants, thrust and performance levels, demonstrated reliability, and advanced state of development. This engine was being developed for the Gemini Space Craft 6 (S/C 6), Orbital Attitude Maneuvering System (OAMS), which required a duty cycle and operating conditions significantly different from the S-IVB ullage control cycle. Table I gives a requirement comparison between the two engine applications. The primary functions of the SE-7 for S-IVB services are to settle the main tank propellants following insertion of the stage in orbit, and provide acceleration during pressurization of the hydrogen tank and chilldown of the J-2 engine. The qualification program was designed to subject the engine to conditions that were equal to, or more severe than, any that would be experienced during S-IVB flight. A chronological listing of the major program milestones is presented in Table II.

Due to the engine contractor's primary commitment to support the Gemini applications for this engine, the selection of the SE-7 carried the restriction that the contractor would not compromise his efforts in support of a qualification program or any engine modification development relating to its use on the S-IVB stage. This necessitated that the qualification test program be conducted at the facilities of either the Marshall Space Flight Center or Douglas Aircraft Company. The engine contractor did, however, lend support in the design of structural modifications to the thrust chamber and in retrofitting these modifications to all previously delivered chambers. This was completed on a non-interference basis during a period of reduced activity at the contractor's facilities.

The engine, pictured in FIG 1, operates with the hypergolic propellants nitrogen tetroxide (N_2O_4) and monomethyl hydrazine (MMH). The combustor body and 40:1 expansion ratio nozzle are fabricated from a high-silica laminate fabric material impregnated with a phenolic resin. The chamber has a one piece graphite composite liner, and the throat is an insert of silicon carbide. The combustion chamber and nozzle are encased within a thin, stainless steel shell with an air gap maintained between the shell and combustor body for alleviation of any outgassing of the ablative material during engine operation.

Chamber cooling is accomplished by the combination of a combustor wall boundary layer of pure fuel (MMH) and the ablative action of the silica laminate portion of the wall itself. The injector has a fuel cooling ring with 16 orifices directed toward the combustor wall,while propellant mixing is accomplished by 16 pairs of fuel-on-oxidizer doublets. Impingement of the fuel and oxidizer takes place at a splash plate that is integral with the injector body. Propellant

TABLE I

PERFORMANCE REQUIREMENTS COMPARISON

	S-IVB	GEMINI
NOMINAL THRUST (LBF.)	72 $\pm$ 5%	94.5
O/F	1.27	1.2
PROPELLANT INLET PRESSURE (PSIA)	195	295
MINIMUM SPECIFIC IMPULSE (SEC)	270	—
NO. OF STARTS	4	MULTIPLE
TOTAL FIRING TIME FOR QUAL (SEC)	640	757
MAXIMUM CONTINUOUS BURN (SEC)	400	97
MISSION DUTY CYCLE (SEC)	454	557

TABLE II

MAJOR PROGRAM MILESTONES

DIVISION OF ATTITUDE CONTROL AND ULLAGE REQUIREMENTS FOR S-IVB	AUGUST, 1963
DECISION TO UTILIZE SE-7 ENGINE FOR ULLAGE CONTROL	MARCH 30, 1964
AUTHORIZATION TO ROCKETDYNE FOR ENGINE PRODUCTION	JANUARY 19, 1965
FIRST QUAL ENGINE RECEIVED	FEBRUARY 18, 1965
INITIATION OF HOT TESTING	MARCH 24, 1965
INITIATION OF VIBRATION PHASE	MAY 11, 1965
QUALIFICATION COMPLETION DATE	AUGUST 17, 1965

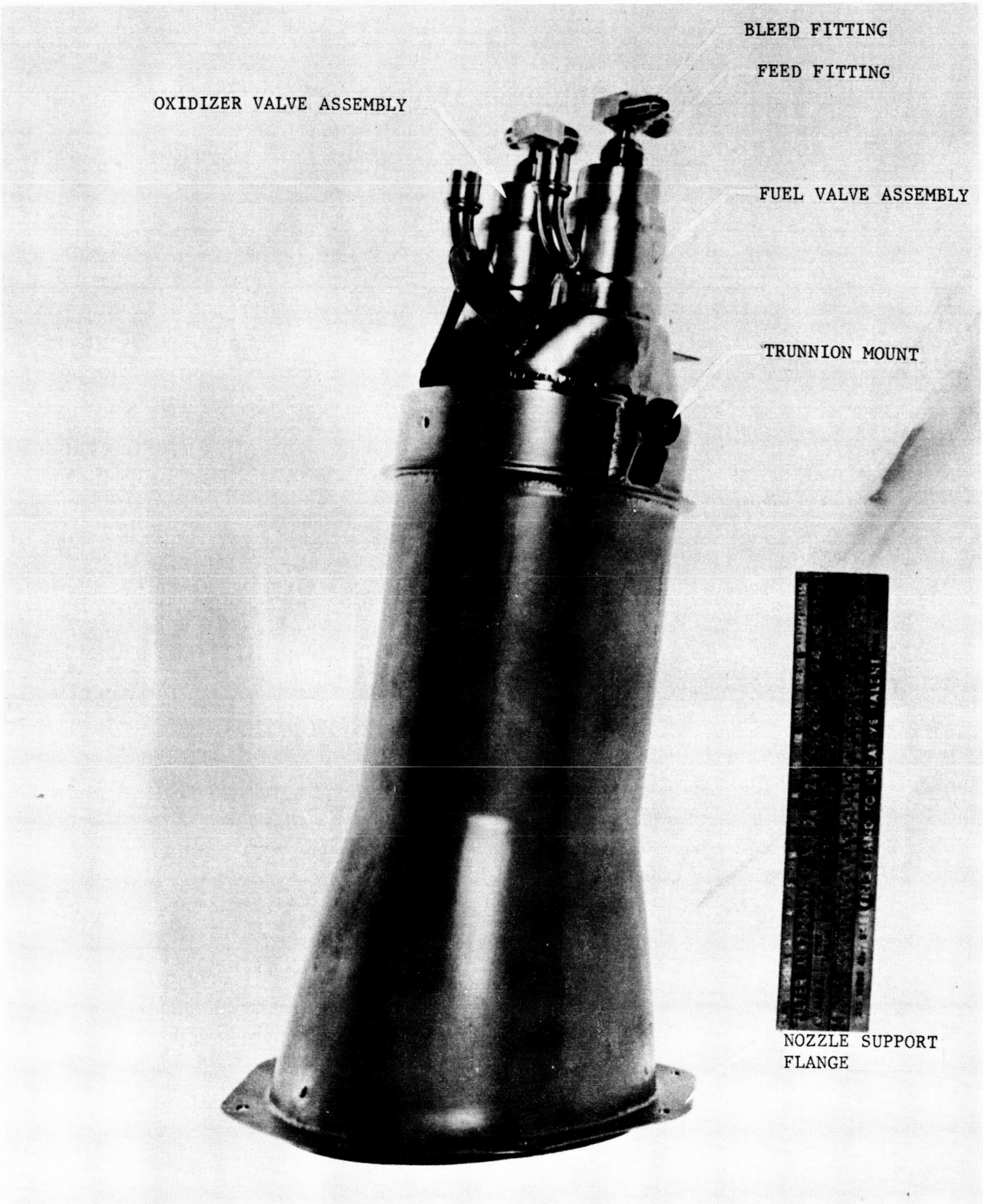


FIG 1 BASIC SE-7 ENGINE AS USED IN GEMINI APPLICATION

flow is controlled by two fast-acting solenoid valves, which are mounted directly to the back of the injector. A chamber pressure measurement fitting was provided on the injector back face and connected to the chamber by means of a 1/8 inch port. The engine has an overall length of 16 inches, an outside major diameter of 4 inches, a throat diameter of 0.710 inch, and a nozzle scarf angle of 10°.

In order for a complete qualification test program to be conducted, four thrust chamber assemblies (TCA) were required. The first unit, TCA 1, proved the engine capable of meeting the requirements of the basic duty cycle under vacuum conditions. TCA 2 proved the service life of the engine when subjected to repeated duty cycles at elevated propellant and thrust chamber temperatures. Tests with TCA 3 investigated the performance effects of off-design operating conditions, while TCA 4 underwent vibration analysis followed by another duty cycle service life examination similar to that of TCA 2. The four engines were subjected to a total of 65 firings, four firings per duty cycle.

A stringent pre-test inspection was given each engine upon receipt from the contractor's manufacturing and checkout facilities. This inspection included visual, weight, dimensional, and X-ray examination followed by propellant valve functional, proof pressure, and leakage tests (See Ref. 1 for procedure). Two engines failed to pass pre-test inspection; one had a leak in the chamber pressure measurement tap, while the other had a short in the propellant valve electrical system. Both were exchanged with the contractor for acceptable engines.

A post-test inspection consisted of essentially the same procedure as the pre-test examination. Very little change in the basic engine characteristics was detectable between pre-test and post-test inspections. The results of the pre-test and post-test inspections were entirely satisfactory, indicating that the fabrication and assembly procedures were acceptable for flight hardware.

During the hot firing phase of the program, the engine demonstrated an impressive service life (in excess of 2600 sec) while maintaining an acceptable performance level at various off-design operating conditions. The off-design tests included propellant inlet pressure and temperature variance as well as engine hardware temperature conditioning. All static tests were conducted at a simulated altitude of approximately 110,000 ft. The most significant incidents of the hot firings were the cracking of the graphite composite chamber liners on two out of the four engines tested, and the cracking of the silicon carbide nozzle insert on one of these two engines. However, this failure did not affect the performance noticeably nor contribute to any further engine abnormalities and was, therefore, not classified as a qualification failure requiring thrust chamber redesign.

Vibration tests indicated that the chamber was weak in the areas of attachment to the APS module. Design modifications were implemented and tested during the vibration/shock qualification tests. Results of vibration tests were satisfactory, and all previously accepted engines were retrofitted with those modifications recommended as a result of the tests. A description of this phase of the program is included in this report.

The program is described in detail under the two major categories of Hot Firing Qualification and Vibration/Shock Qualification. Appendix A presents a typical copy of the hot firing measurement program. The hot firing test procedure is outlined in Appendix B, and selected data from these tests is found in Appendix C. Data from the vibration/shock tests is contained in Appendix D.

ACKNOWLEDGEMENTS

The successful completion of this qualification program was made possible through the cooperative spirit displayed by the various groups - both government and contractor - participating in the effort.

The Environmental Test Section of Test Laboratory was responsible for all hot firing activities and reported on this phase of qualification in a seperate report (Reference 2). This document was used almost verbatim in the discussion of hot firing qualification.

Vibration/shock qualification was conducted by the Applied Mechanical Research Branch of the Propulsion and Vehicle Engineering Laboratory with data analysis performed by the Vibration and Acoustics Branch of that Laboratory.

Pre-test and post-test inspection was conducted by the Mechanical Test Branch and the Mechanical Analysis Branch of the Quality and Reliability Assurance Laboratory.

Considerable engineering support was received throughout the program from the SE-7 engine contractor (Rocketdyne) and the S-IVB stage contractor (Douglas Aircraft Company).

HOT FIRING QUALIFICATION

Test Requirements

Four Gemini SE-7 engines were subjected to Qual hot firing tests in accordance with the requirements specified below:

TCA 1 - Test through one simulated mission duty cycle (see Table III) with ambient temperature propellants and engine.

TCA 2 - Pre-soak the engine at 150°F before static firing, and then fire in accordance with the Qual duty cycle with 120°F propellants. Repeat duty cycle until castastrophic failure occurs (as defined in note 2 of Table III) or until successful completion of the fourth duty cycle.

TCA 3 - Test for performance evaluation at off design values of temperature and valve inlet pressures as tabulated in Table IV. Upon completion of performance evaluation tests, static fire with valve inlet pressures of 400 psia (corresponding to maximum system transient pressure) for five seconds.

TCA 4 - After specified vibration/shock qualification, static fire in accordance with the Qual duty cycle listed in Table III with ambient temperature propellants and engine. Repeat the duty cycle until catastrophic failure occurs (as defined in note 2 of Table III) or until successful completion of the fourth duty cycle. A typical test procedure is contained in Appendix B.

Description of Test Facility

All tests were conducted at the Storable Propellant Facility of the MSFC Test Laboratory. The basic items comprising the facility were: a test stand; two 100-gallon, 304 stainless steel storage tanks (one per propellant); two 26-gallon, 304 stainless steel run tanks (one per propellant); an altitude cell; an engine diffuser; an exhaust gas cooling duct; a mechanical vacuum pump; a two-stage steam

TABLE III

QUAL DUTY CYCLE

Firing No.	On Time (Seconds)	Off Time (Minutes)	Total On Time (1) (Seconds)	Elapsed Time (Minutes)
1	130	120	145	122.2
2	70	120	215	243.4
3	400	30	615	280.0
4	40		655	280.7
5 (2)	Repeat duty cycle			

NOTE: 1. Includes 10 seconds of Rocketdyne acceptance testing and 5 seconds of MSFC testing to set run conditions.

2. If catastropic failure does not occur prior to or during firing number 4, the duty cycle is repeated until catastropic failure occurs. Catastropic failure is defined as a condition at which further operation would endanger the life of the vehicle. Specifically it includes:

   a. Lack of capability to stop propellant flow (engine valve failure).

   b. Any flow or leakage of propellants or combustion products from locations other than the TCA exit.

   c. Decay in chamber pressure to less than 75 psia or thrust to less than 55 pounds.

   d. Chamber skin temperature in excess of red-line value (650°F).

TABLE IV

QUAL ENGINE NO. 3 - OFF DESIGN TESTING

Run No.	Run Duration	Propellant Temp. (°F)	Valve Inlet Pressure (psia)		Engine Temp. (°F)
			Oxidizer	Fuel	
1	5	+20	175	175	Ambient
2	5	+20	195	195	Ambient
3	5	+20	275	275	Ambient
4	5	Ambient	175	175	Ambient
5	5	Ambient	195	195	-40
6	5	Ambient	275	275	Ambient
7	5	+120	175	175	Ambient
8	5	+120	195	195	Ambient
9	5	+120	275	275	Ambient
10	5	+20	195	195	-40
11	5	+120	195	195	+150
12	5	Ambient	195	195	+150
13	5	Ambient	275	175	Ambient
14	5	Ambient	175	275	Ambient

NOTE: Upon completion of the above performance evaluation tests, hot fire the engine for five (5) seconds with the valve inlet pressures set at 400 psia, which corresponds to the valve inlet burst pressure.

ejector; an altitude chamber isolation (vacuum) valve; facility valves and tubing; two scrubbers (one per propellant; a floor deluge system; propellant tank and feed line heaters; a control room; and a measuring center. See FIG 2 for an overall facility picture and FIG 3 for a schematic illustrating the pressure profile throughout the altitude system. FIG 4 contains a propellant piping schematic. The engine was mounted in the altitude cell as shown in FIG 5.

Propellant vents, drains, and bleeds were routed to scrubbers that were filled with crushed limestone and water. The overflow from each scrubber was directed to a holding pond containing water and neutralization agents (sodium bicarbonate for N_2O_4 and sodium hypochlorite for MMH). All valves in contact with the propellants or their vapors were of 304 stainless steel with teflon seats. Tubing and fittings used in the propellant piping systems were of 304 or 316 stainless steel.

For firings at elevated temperatures, the propellants were heated by three 2-kilowatt band heaters wrapped around each run tank and by a 50-watt tape heater wrapped around each propellant feed line. The engine was heated by two 250-watt infrared lamps. Cooling of the propellants and the engine was achieved by flowing LN_2 through copper tubing coiled around the tanks, the feed lines, and the engine.

Dry gaseous nitrogen was used as the propellant tank pressurizing media and for purging the propellant lines and engine. A 20 psig GN_2 "blanket" pressure was maintained in each propellant tank between test days, and at the end of each test day, the engine was purged with GN_2 by simultaneously opening the main engine valves with the steam ejector on. After several minutes of GN_2 purge, the purge valves were closed. The engine valves were left open and the engine and feed lines were "vacuum" purged with the steam ejector. This purging procedure removed all propellant downstream of the facility prevalve. After each test, propellant was left standing between the run tank and the prevalve in the section of feed line that contained the flowmeters.

Protective clothing and breathing equipment were worn by all personnel involved in any operation where there was possible exposure to the propellants or their vapors. The protective clothing consisted of a neoprene coated nylon suit including pants, coat, and

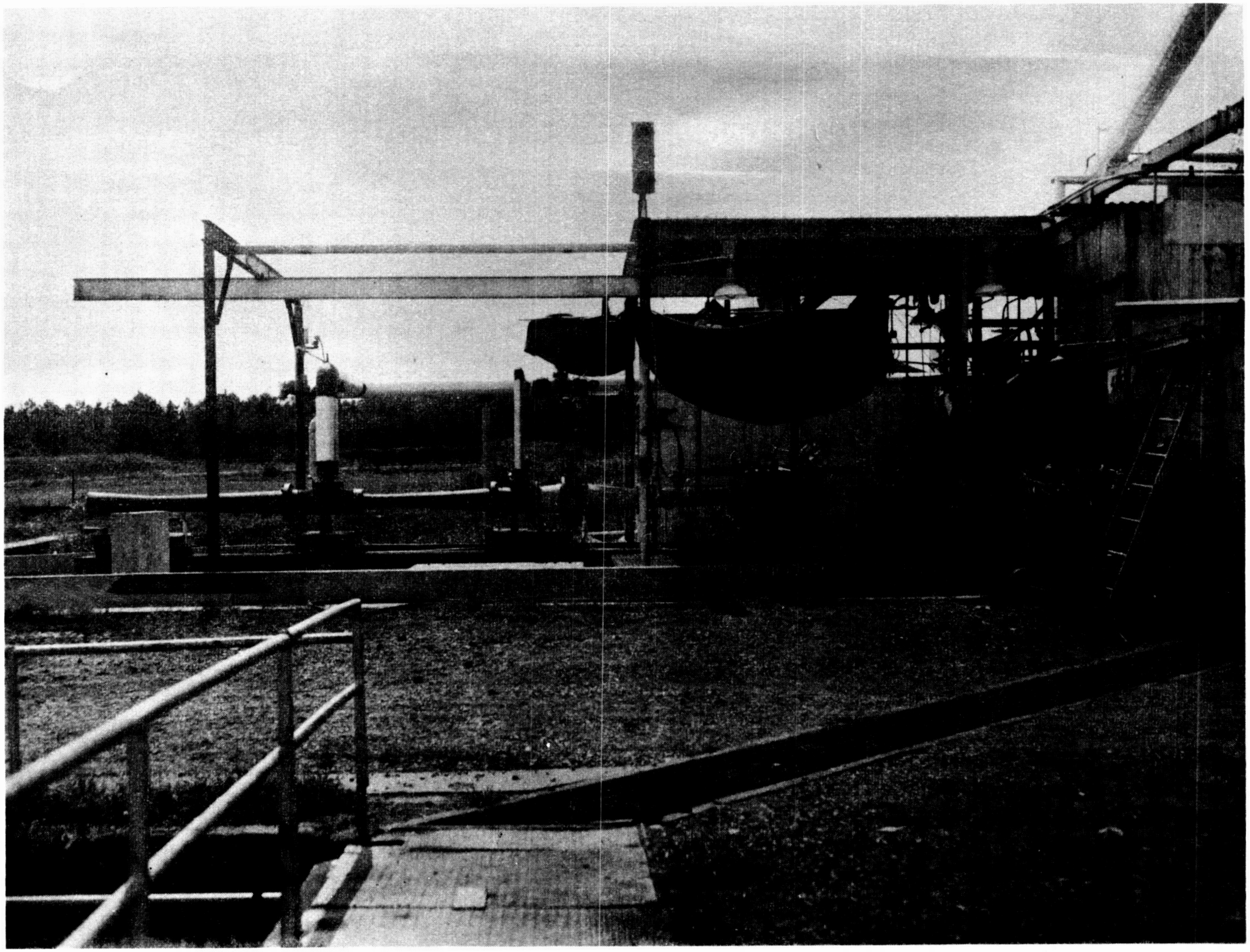
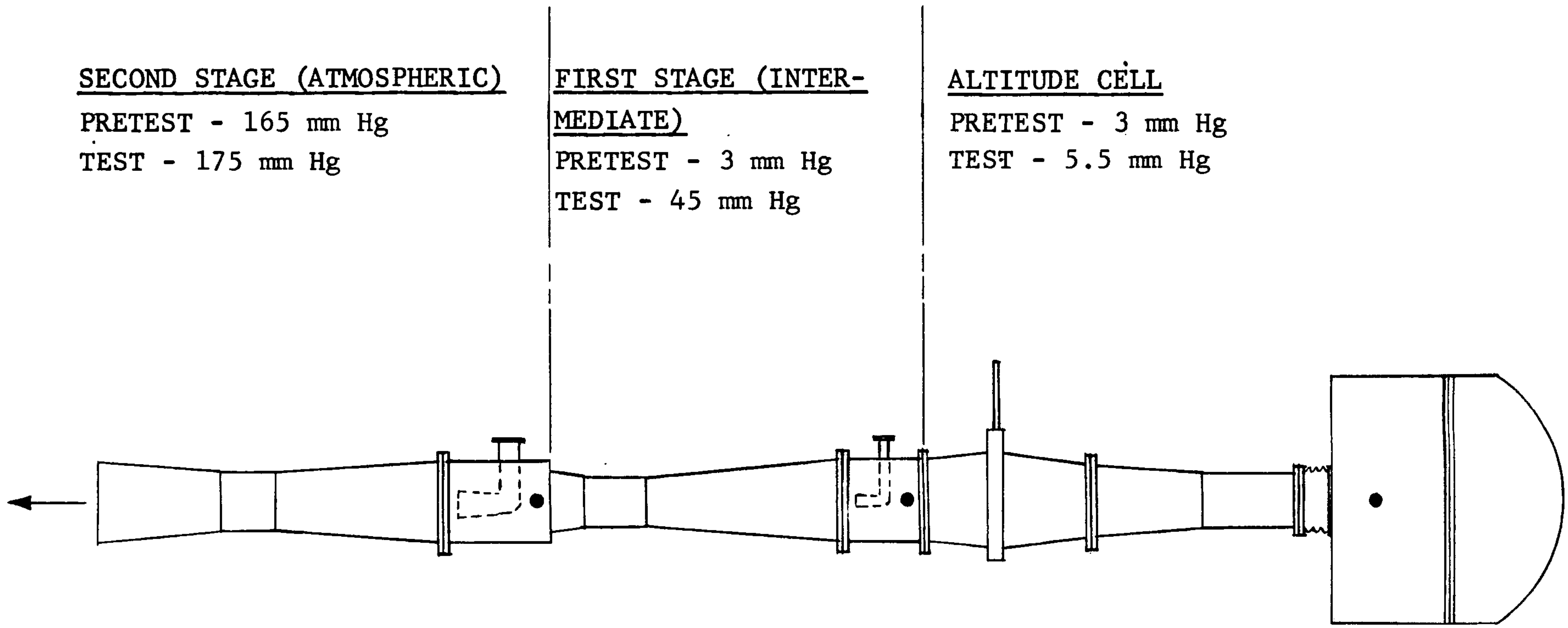
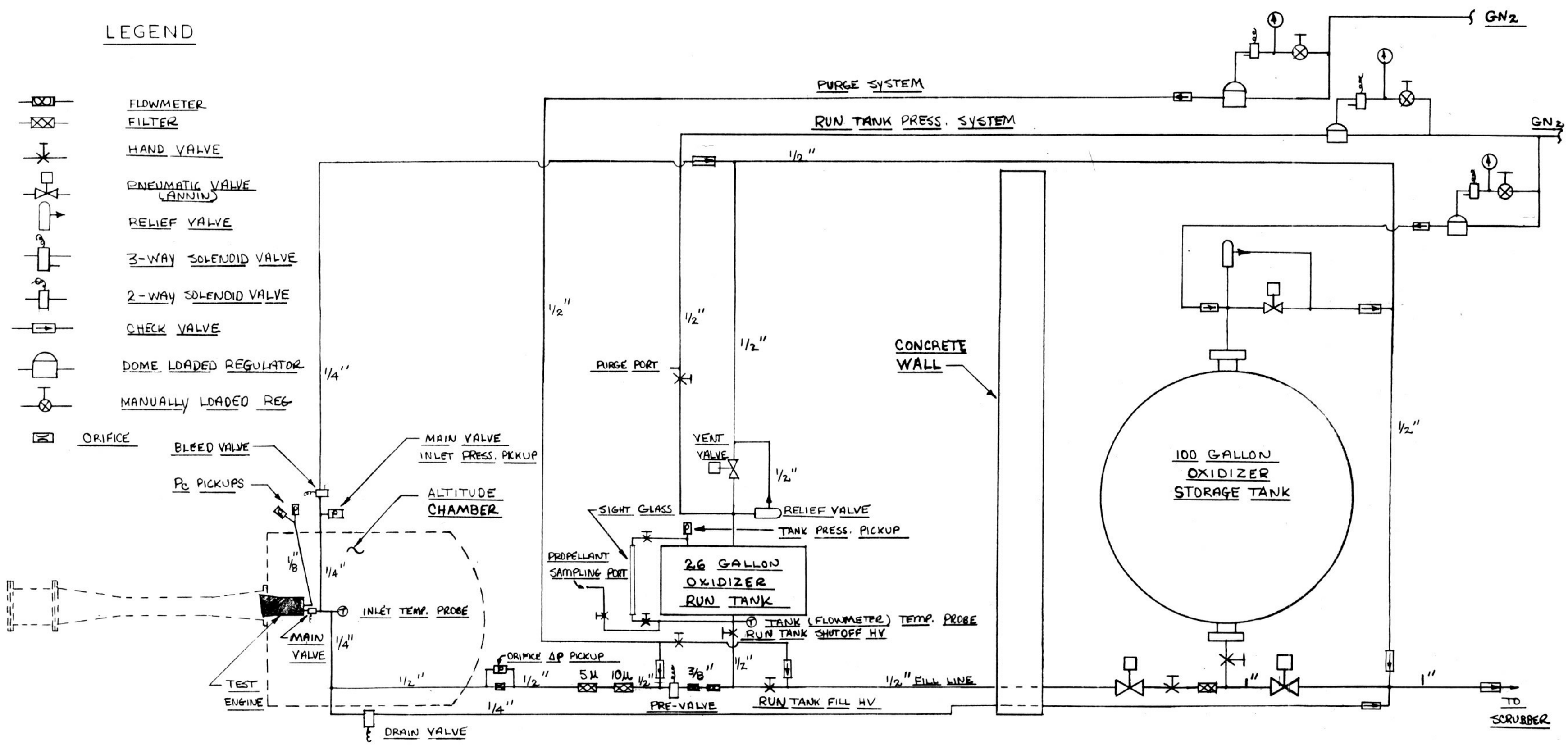


FIG 2 SE-7 TEST FACILITY



NOTE: PRESSURE PICKUP POINTS INDICATED BY BLACK DOTS

FIG 3 PRESSURE PROFILE IN STEAM EJECTOR AND ALTITUDE CELL SYSTEM



NOTE: FUEL SYSTEM SIMILAR EXCEPT NO STORAGE TANK IS USED AND FUEL IS TANKED DIRECTLY FROM 55 GALLON DRUM

FIG 4 TYPICAL PROPELLANT PIPING SYSTEM, SE-7 ALTITUDE FACILITY

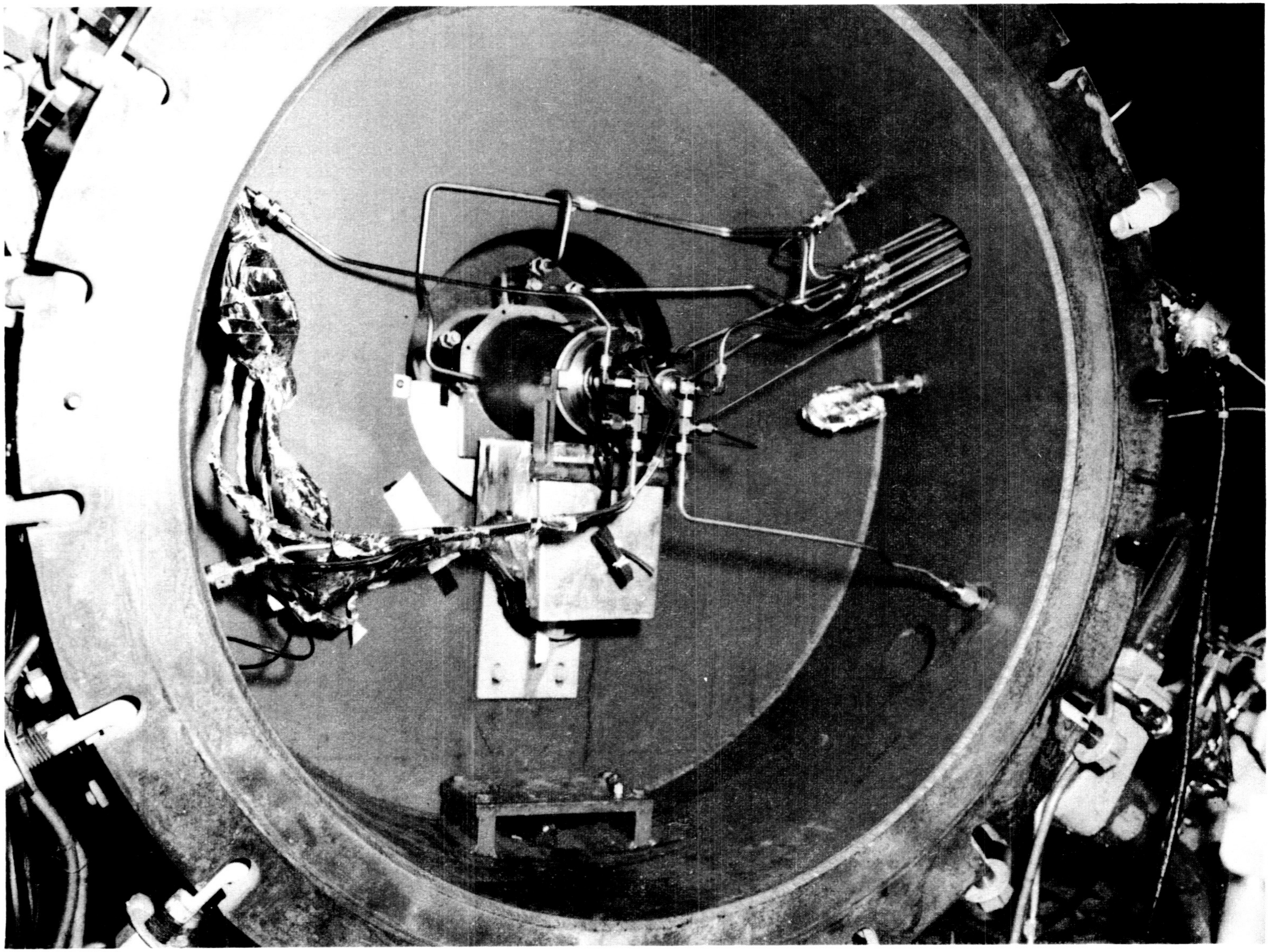


FIG 5 TCA 1 INSTALLATION IN ALTITUDE CHAMBER

hood, neoprene boots, and neoprene gloves. Air masks with demand type regulators were used for respiratory protection.

Instrumentation

Fifty measurements were taken in most of the tests conducted in this program. These measurements included 18 pressures, 22 temperatures, four flowrates, one thrust, two voltages, and two currents. Redundant measurements (two each) were taken on oxidizer flow, fuel flow, and chamber pressure. A description of each measurement is contained in Appendix A (typical copy of the measuring program).

The nominal instrumentation accuracy was determined to be $\pm$ 1% of the calibrated range for strip chart measurements and $\pm$ 3% of the calibrated range for oscillograph measurements. Exceptions to the oscillograph accuracy are the propellant flowrates that are determined to be accurate to $\pm$ 1%.

Thrust Measurement

The FluiDyne flex-cell, a parellelogram flexure that incorporates a force measuring element (strain gage) as an integral part, was used for thrust measurement on the first three engines due to its simplicity and encouraging results obtained in a test of a prototype engine. However, during the relatively long firing periods of the Qual testing, radiation from the engine exhaust gases and diffuser inlet produced a zero shift effect on this device. This problem was substantially alleviated by enclosing the flex-cell in an asbestos lined aluminum box. This fix, however, did not entirely eliminate the zero shift problem, particularly during the environmental conditioning tests. The relatively large metal mass of the flex-cell made it extremely sensitive to temperature. Also, an electrical malfunction in the flex-cell produced invalid thrust data on TCA 2. In this case, the thrust for each firing was computed based on Pc, throat area, and C_f data generated by Rocketdyne during acceptance testing and by Test Laboratory during Qual testing on TCA 1 and 4.

The thrust measuring system for TCA 4 used a Revere strain gage type load cell with the engine and its mounting bracket supported by four flexures. The rear of the engine mounting bracket was butted against a rigidly supported load cell (see FIG 6 for a photograph of the thrust measuring system). This system encountered a large instrumentation zero shift whenever the test cell was evacuated. This shift was apparently due to the interaction between the thrust mounting assembly and the altitude chamber walls, because the assembly was welded to the walls. However, the shift was easily zeroed out after the test cell was evacuated.

Also, in each test of TCA 4 the thrust trace started decaying at approximately X + 20 seconds. The total amount of thrust decay during the test was equal to the zero shift indicated at the end of the test. The zero shift was determined to be due to heat being radiated from the engine diffuser to the flexures. This was substantiated by using a "sun gun" to apply heat to the flexures and monitoring the zero shift on the load cell. Because of the zero shift effect on each thrust measuring system as related to firing duration, thrust accuracy of $\pm$ 1% was retained by using data obtained at 10 and 15-second slice times. The performance values included in this report were based on this data.

Propellant Flow Measurement

Propellant flow data were recorded using Cox and Spaco rotating vane type flowmeters. The Cox flowmeters, furnished by Rocketdyne, were calibrated in the propellant media (MMH or N_2O_4) at a temperature of approximately 70^0F. The Spaco Flowmeters used to measure fuel flow were calibrated with water at 70^0F; those used to measure oxidizer flow were calibrated with N_2O_4 at 70^0F. Redundant measurement of each propellant flow was accomplished by placing two flowmeters in series. A propellant flow check was performed prior to each test by flowing propellant through a fixed orifice and recording the flowrate. Based on comparative flow data from series measurements in the fuel system, it was determined that water calibrated meters could be used in measuring MMH flow within $\pm$ 1% error.

This was not the case for the oxidizer. As stated above, all oxidizer flow data was obtained using meters calibrated in N_2O_4 at 70^0F. There was some concern over the accuracy of the flow data

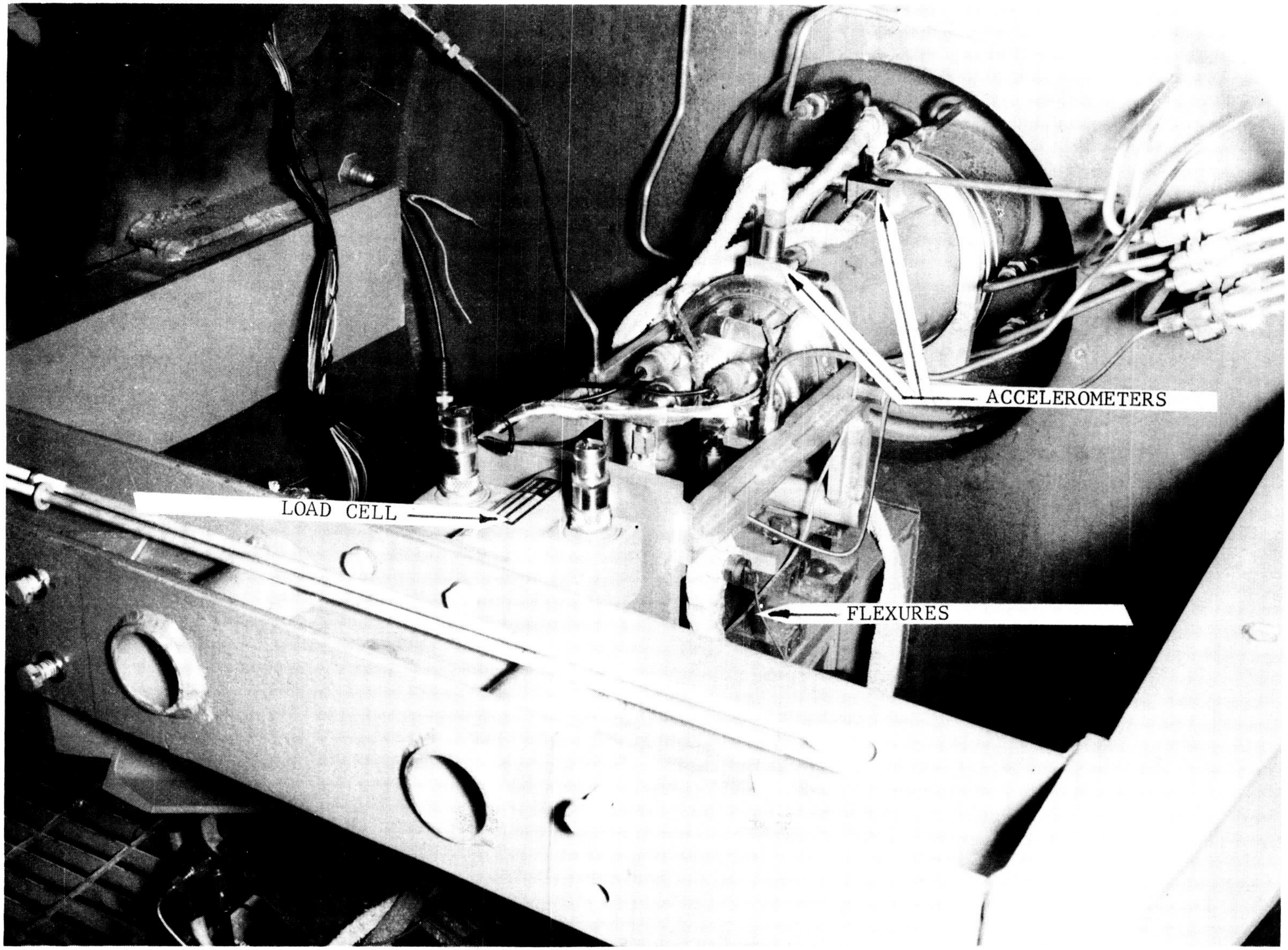


FIG 6 THRUST MEASURING SYSTEM USED ON SE-7 TCA 4

obtained using the 70°F calibrations when the propellants were thermally conditioned at the temperature limits (+ 20°F and + 120°F) dictated by the Qual Test Program. The Test Laboratory Instrumentation Development Branch conducted a limited investigation of this matter. The investigation consisted of calibrating the same type meters with water at various temperature levels. Based on the results, it was determined that an additional 2% flow deviation could be encountered at the temperature extremes of the Qual Program when using 70°F calibration data. This information, coupled with the standard instrumentation error of ± 1%, could result in flow accuracies of ± 3%.

Instrument Calibration

All pressure and thrust instruments were calibrated before each test. Pre- and post-test calibrations were usually taken on such measurements as thrust and environmental pressure. The transducers, which measured engine chamber pressure and propellant valve inlet pressures, were post calibrated. In the case of deviation between the pre- and post-test calibrations, the best calibration in the judgement of the test engineer was used for data reduction purposes. Electro-mechanical checkouts were performed to assure that all valves and cutoffs were operating satisfactorily before test initiation. Samples of each propellant were obtained for purity analysis after each propellant tank fill.

Electrical Control System

The electrical control system provided remote control for all valves in the test system with the exception of manual valves and the pressure operated steam regulator valve. The control system was such that all remote controlled valves could be operated individually or incorporated in an automatic sequence circuit. The electrical control power of 28 volts DC was supplied from a Nobatron DC generator.

The control sequence contained safety factors that made it impossible to obtain engine ignition until certain predetermined facility conditions were satisfied, such as proper valve position and adequate GN_2 supply pressure. Major signals - valve positions, ignition, cutoff, etc. - in the firing sequence were monitored on Easterline - Angus 20-pin recorders.

The test cell pressure recorder was wired into a cutoff circuit, and a test was automatically terminated if this pressure exceeded 40 mm Hg (67,000 feet simulated altitude). Redline values were also assigned to thrust, chamber pressure, and isolation valve inlet temperature (see Appendix A). Observers in the data recording center were instructed to terminate a test if the redline values were exceeded.

RESULTS OF HOT FIRING TESTS

Sixty-five hot firing tests were successfully conducted between March 24 and August 17, 1965. These tests were conducted on four Gemini OAMS engines in accordance with the plan specified in the previous section of this report. The following are general observations concerning these tests.

Engine Valve Signatures

The opening and closing times of the main engine valves remained constant for all tests. The opening time for each valve (oxidizer and fuel) was 17 $\pm$ 2 milliseconds; the closing time was 15 $\pm$ 2 milliseconds. Typical main valve signatures (voltage and current traces) for TCA 1 and 4 are shown in FIG 7 and 8, respectively.

TCA 1

TCA 1 (Rocketdyne S/N 4070490) was successfully tested through one duty cycle with ambient temperature hardware and propellants (approximately 50^{o}F). Post-test inspection revealed a cracked and "buckled" segment in the combustion chamber liner near the injector face (FIG 9) and a hairline crack in the liner leading from the cracked segment to the front edge of the throat insert. These cracks were verified by X-ray analysis. No other deformities were noted. The throat diameter remained unchanged.

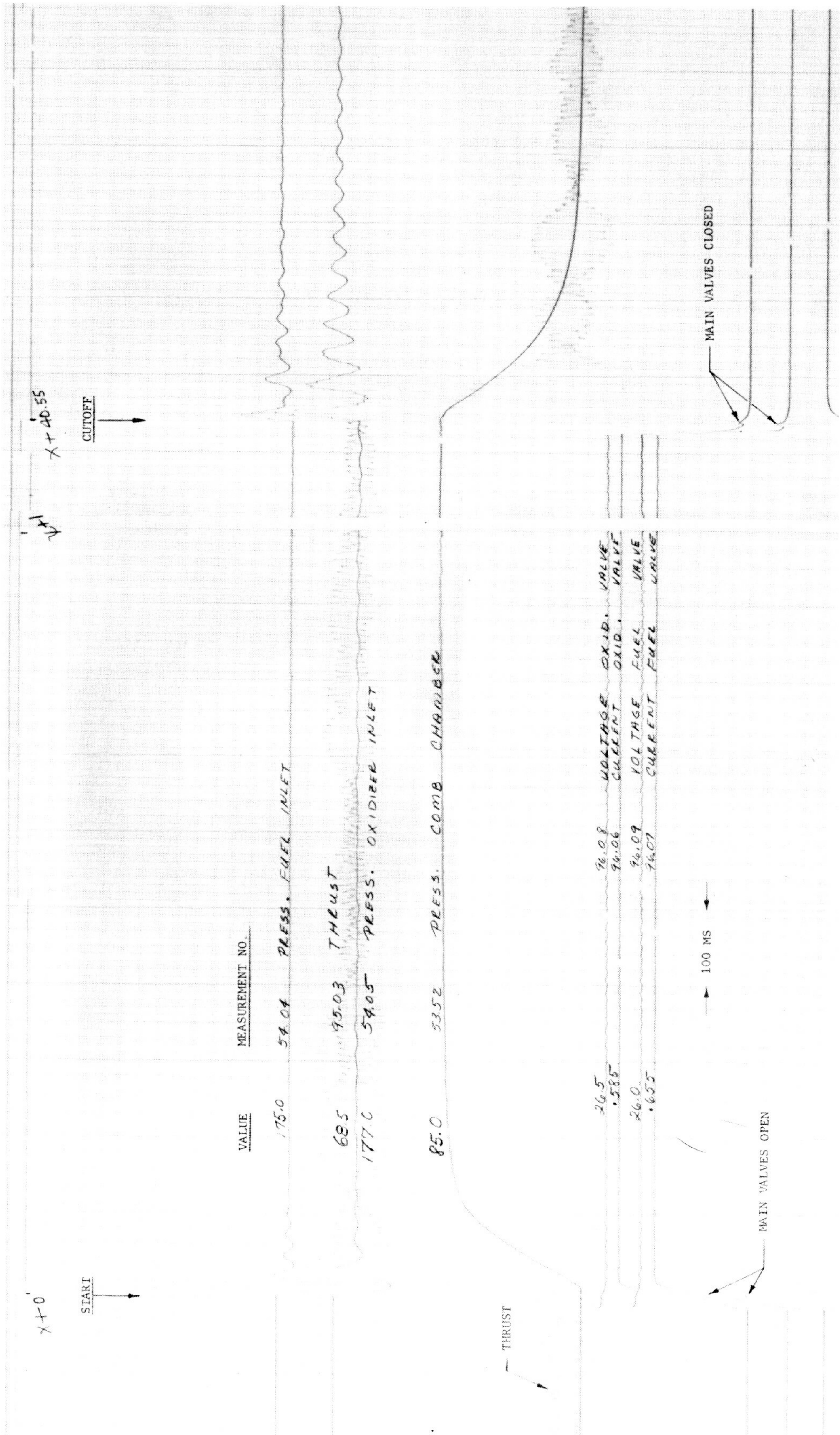


FIG 7 TYPICAL OSCILLOGRAPH TRACES (TCA 1, TEST C-028-39)

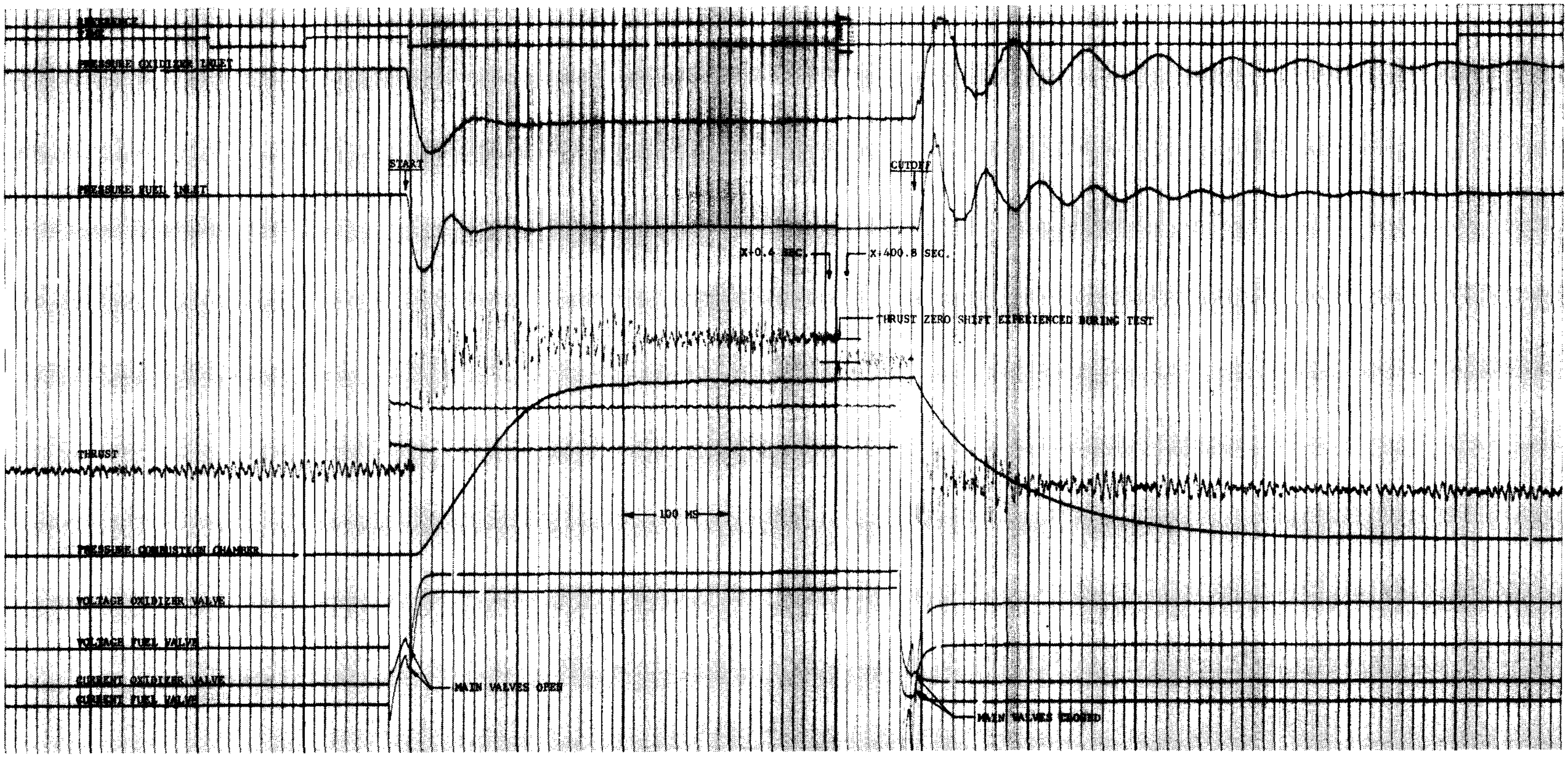


FIG 8 OSCILLOGRAPH TRACES ON TCA 4 - TEST C-028-114

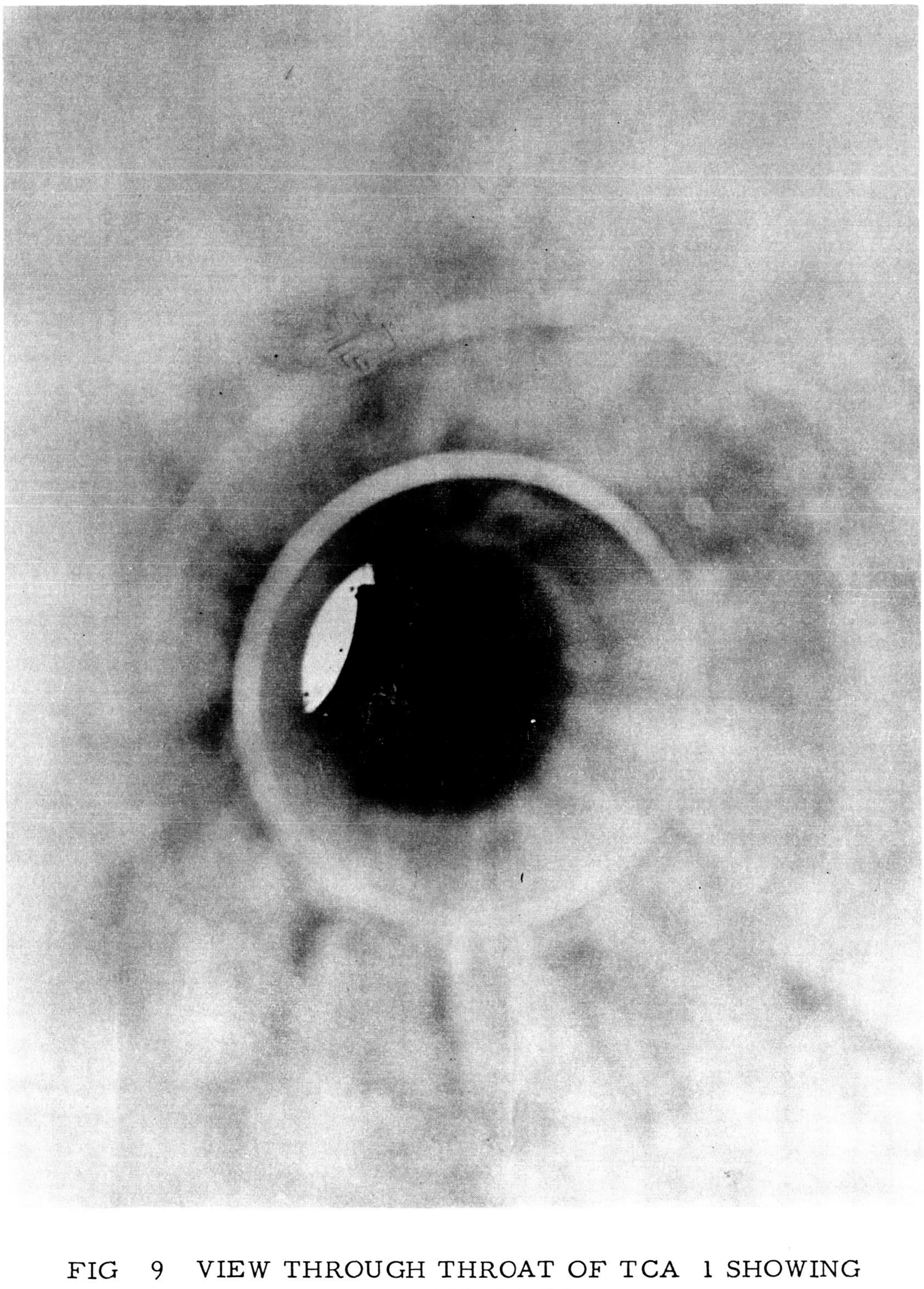


FIG 9 VIEW THROUGH THROAT OF TCA 1 SHOWING CRACKED SEGMENT OF CHAMBER LINER RESULTING FROM ONE DUTY CYCLE HOT FIRING

TCA 2

TCA 2 (Rocketdyne S/N 4071853) was successfully tested through four duty cycles with hot propellants (120°F). Prior to each duty cycle the engine was "pre-soaked" to a temperature of 150°F. This temperature was determined by monitoring temperatures measured by thermocouples on the engine outer skin and on the inside surface of the engine throat. The infrared lights used to heat the engine were cycled on and off until both sets of thermocouples read approximately 150°F.

Visual inspections of the engine after each duty cycle revealed no cracks or other deformities. There was no measurable increase in the throat diameter.

TCA 3

Twenty-nine successful five-second tests were conducted on TCA 3 (Rocketdyne S/N 4069234) at off design values of propellant and engine temperature and valve inlet pressure. Propellant temperature was varied from +20°F to +120°F, engine temperature from -40°F to +150°F, and valve inlet pressure from 175 psia to 375 psia. The tests were conducted at combinations of the above conditions as described in Table IV. The engine temperature was set using the inside throat thermocouple and the engine outer skin thermocouples.

A visual inspection of the engine was made after the series of tests using hot propellants/hot engine and hot propellants/ambient engine. No damage to the chamber liner or throat insert was noted. Similarly no damage was noted after the series of tests utilizing ambient propellants/hot engine and ambient propellants/ambient engine. However, post-test visual inspection after the series of tests using cold propellants/ambient engine, ambient propellants/cold engine, and cold propellants/cold engine - and the hot fire burst pressure test (valve inlet pressure = 375 psia) - revealed multiple cracks in the chamber liner and two hairline cracks in the throat insert. These cracks were substantiated by X-ray photographs. There was no measurable increase in the throat diameter.

TCA 4

TCA 4 (Rocketdyne S/N 4071863) was successfully tested through four duty cycles at ambient temperature conditions (propellant and engine). Prior to hot firing, the engine was vibrated in an S-IVB simulated test fixture at P&VE Laboratory.

The first duty cycle attempted on the engine was terminated after 209 seconds firing time due to excessive pressure oscillations in the fuel feed system. An investigation revealed that the propellant tank pressurizing GN_2 was flowing back through a check valve into the purge system and in turn into the fuel feed line downstream of the facility prevalve. This problem was corrected and four successful duty cycles were then completed.

Visual inspection and X-rays of the engine after the first duty cycle revealed no cracks. Visual inspection of the engine after the second duty cycle revealed an apparent crack about 1/2-inch long in the chamber liner. This crack was located at the 10 o'clock position on the opposite side of the chamber from the fuel valve. Further inspection of the engine after completion of the third and fourth duty cycles revealed that this was not a crack but rather an eroded ring in the surface of the liner. The erosion encompassed 360^0 of the liner after completion of the fourth duty cycle. X-rays further substantiated that there were no cracks completely through the liner. The throat diameter was .7111 in. before and after the fourth duty cycle.

That higher performance was obtained on this engine than on the other three engines tested is evidenced by the data contained in Appendix C. This increase in performance was coupled with a lower O/F ratio because of increased fuel flowrate due to a larger diameter fuel trim orifice.

A summary of the test data obtained on all four engines is contained in Appendix C. This data includes both site data as read and data adjusted to standard conditions. Standard operating conditions for these engines include fuel and oxidizer inlet pressures = 195 psia, fuel density = 54.66 lb/ft^3, oxidizer density = 89.85 lb/ft^3, and environmental pressure = 0 psia. Calculated thrust, and consequently, calculated I_{sp} data were used on the tests conducted on TCA 2 because invalid thrust data was obtained due to malfunction of the load cell.

Appendix C also presents typical data (from one test of each condition) on TCA 3. All engines operated within the rate performance specifications (72 $\pm$ 3 pounds thrust, 100 $\pm$ 5 psia chamber pressure). Representative oscillograph traces illustrating combustion chamber pressure, thrust, main valve inlet pressures, and main valve voltages and currents for TCA 1 and 4 are presented in FIG 7 and 8, respectively. The traces shown in FIG 7 are also typical for TCA 2 and 3. The thrust traces in FIG 7 and 8 differ because different thrust measuring systems were used.

During all tests the engine outer skin temperatures remained below the 650^{0}F limit with the exception of the nozzle exit temperature (#7) on TCA 1 which reached 681^{0}F 84 seconds after the completion of the 400-second test. This temperature increase was caused by radiation from the uncooled diffuser inlet and consequently was not a valid skin temperature indication. A time-temperature history of the outer skin (throat) temperature for the complete duty cycle on TCA 1 is presented in FIG 10. Similar curves for the four duty cycles conducted on TCA 2 and 4 are presented in FIG 11 and 12, respectively. These figures show that there was very little difference in the temperature profile for each successive duty cycle. Curves depicting the rate of increase of the engine outer skin temperatures for the 400-second duration tests conducted on TCA 1 and 2 are presented in FIG 13 and 14, respectively.

An examination of the test data obtained on TCA 2 (120^{0}F propellants) indicated that there was some propellant GN_2 dilution at the end of the third firing and throughout the fourth firing of each of the four duty cycles. This was evidenced by slightly lower engine performance than on the earlier firings. The dilution of GN_2 in the propellants was apparently a result of the hot propellants remaining under full run tank pressure for a long period of time (in excess of four hours).

Vibration Measurement

Weld failures around the exit mounting flange and the trunnion mount during vibration testing of an engine that had previously been fired prompted the measurement of engine vibrations on the second and fourth Qual engines. Vibrations in the longitudinal, vertical, and transverse planes were measured using accelerometers during the

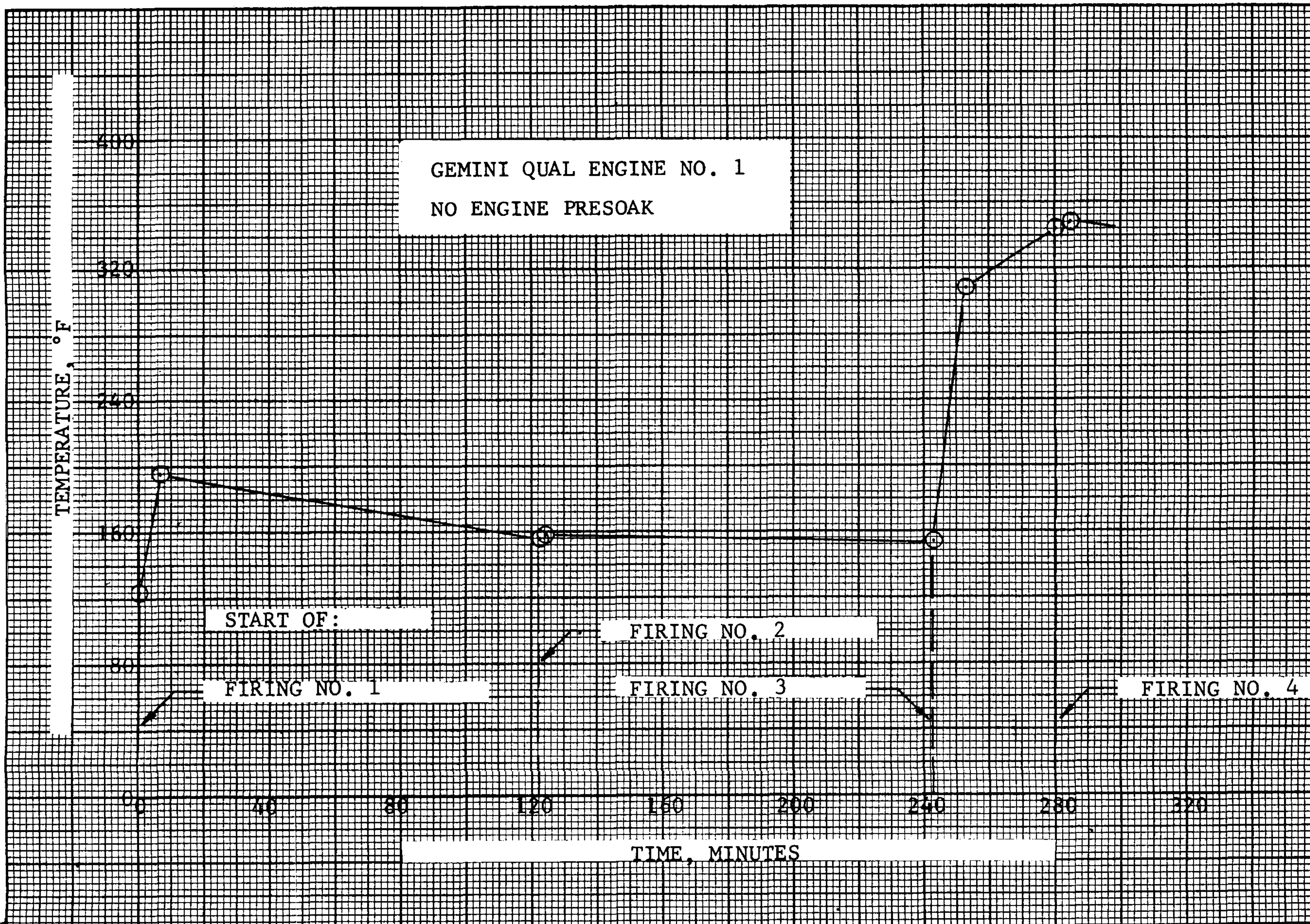


FIG 10 OUTER SKIN (THROAT OUTSIDE) TEMPERATURE VERSUS TIME (TCA 1)

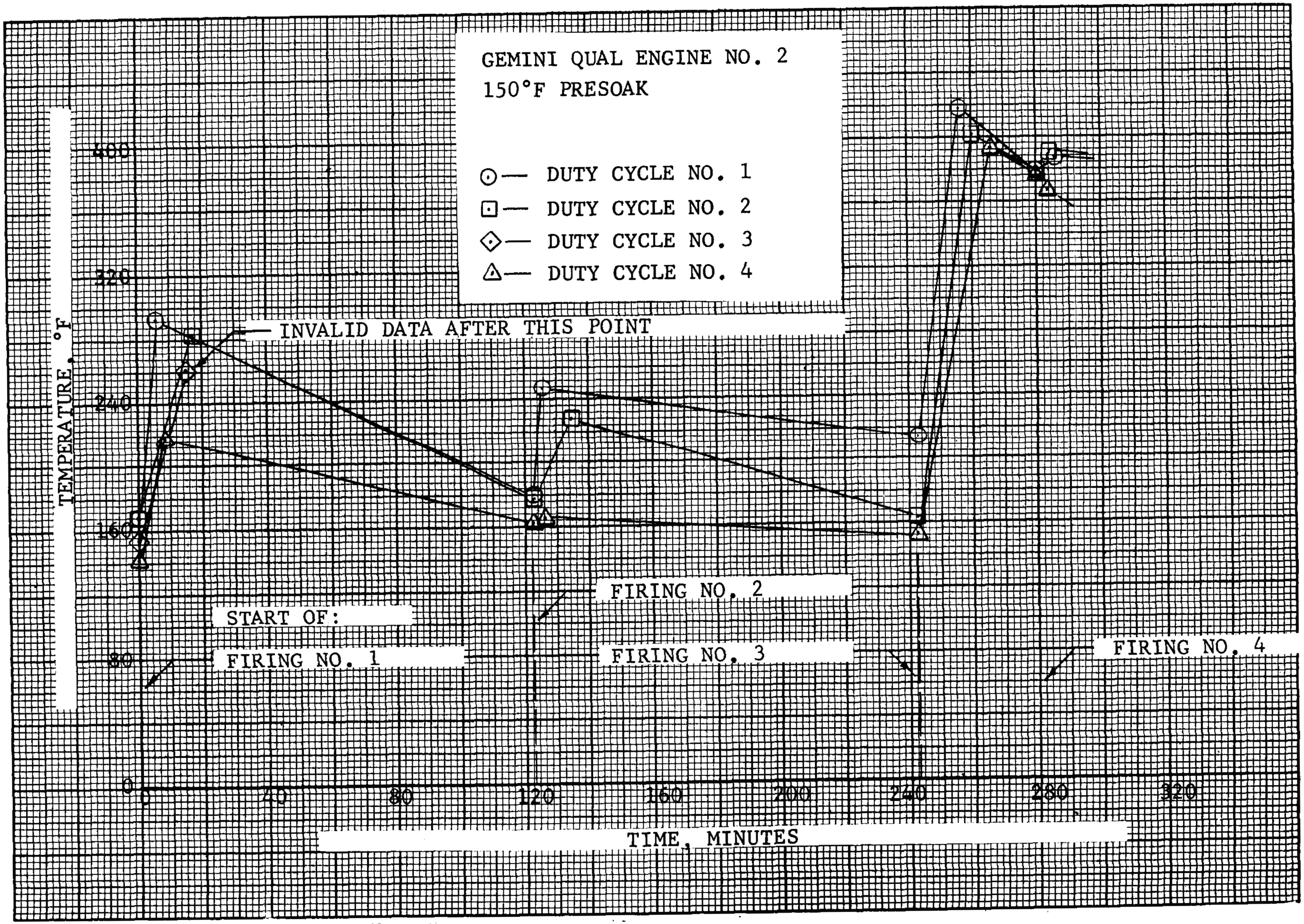


FIG 11 OUTER SKIN (THROAT OUTSIDE) TEMPERATURE VERSUS TIME (TCA 2)

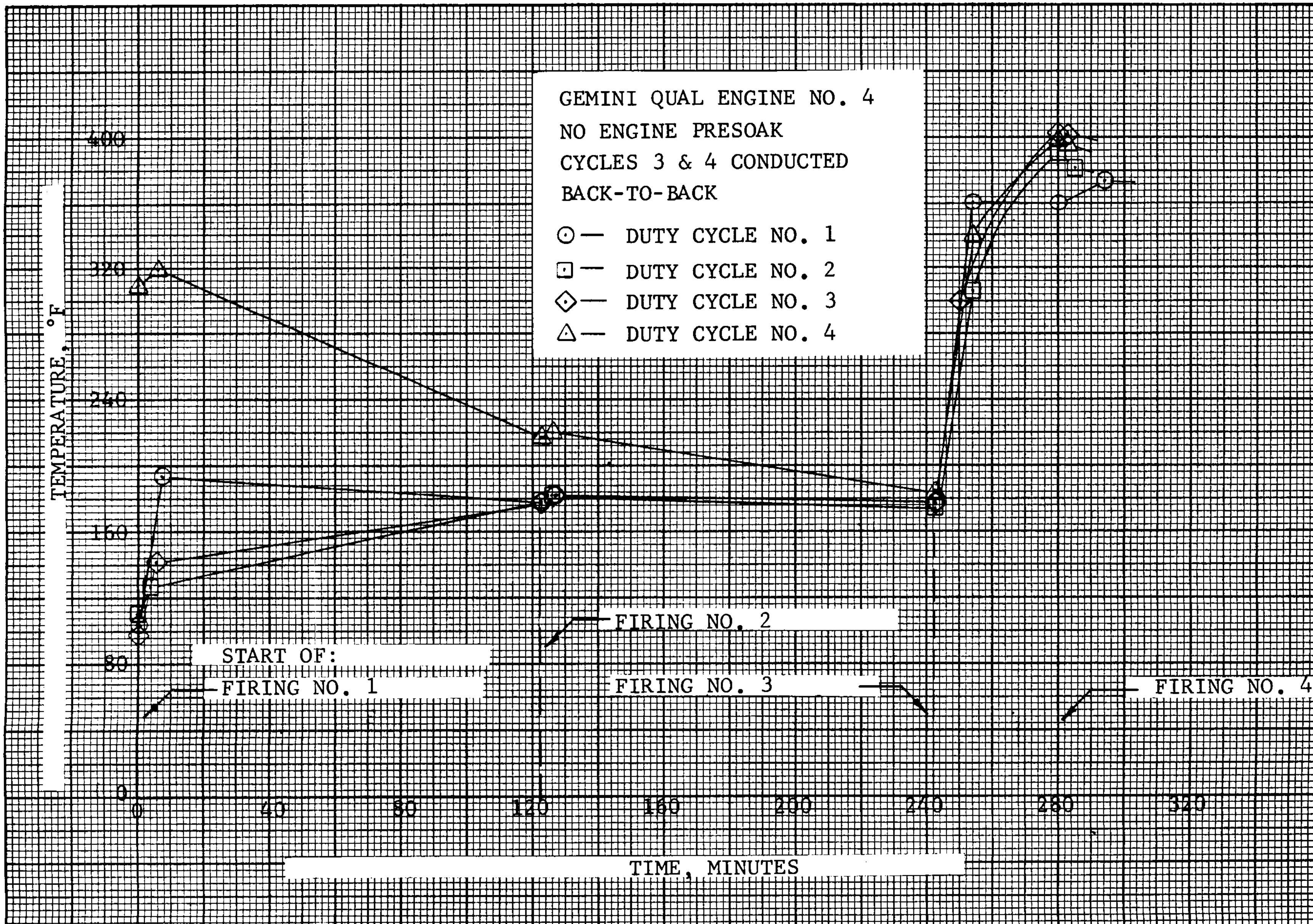


FIG 12 ENGINE OUTER SKIN (THROAT OUTSIDE) TEMPERATURE VERSUS TIME (TCA 4)

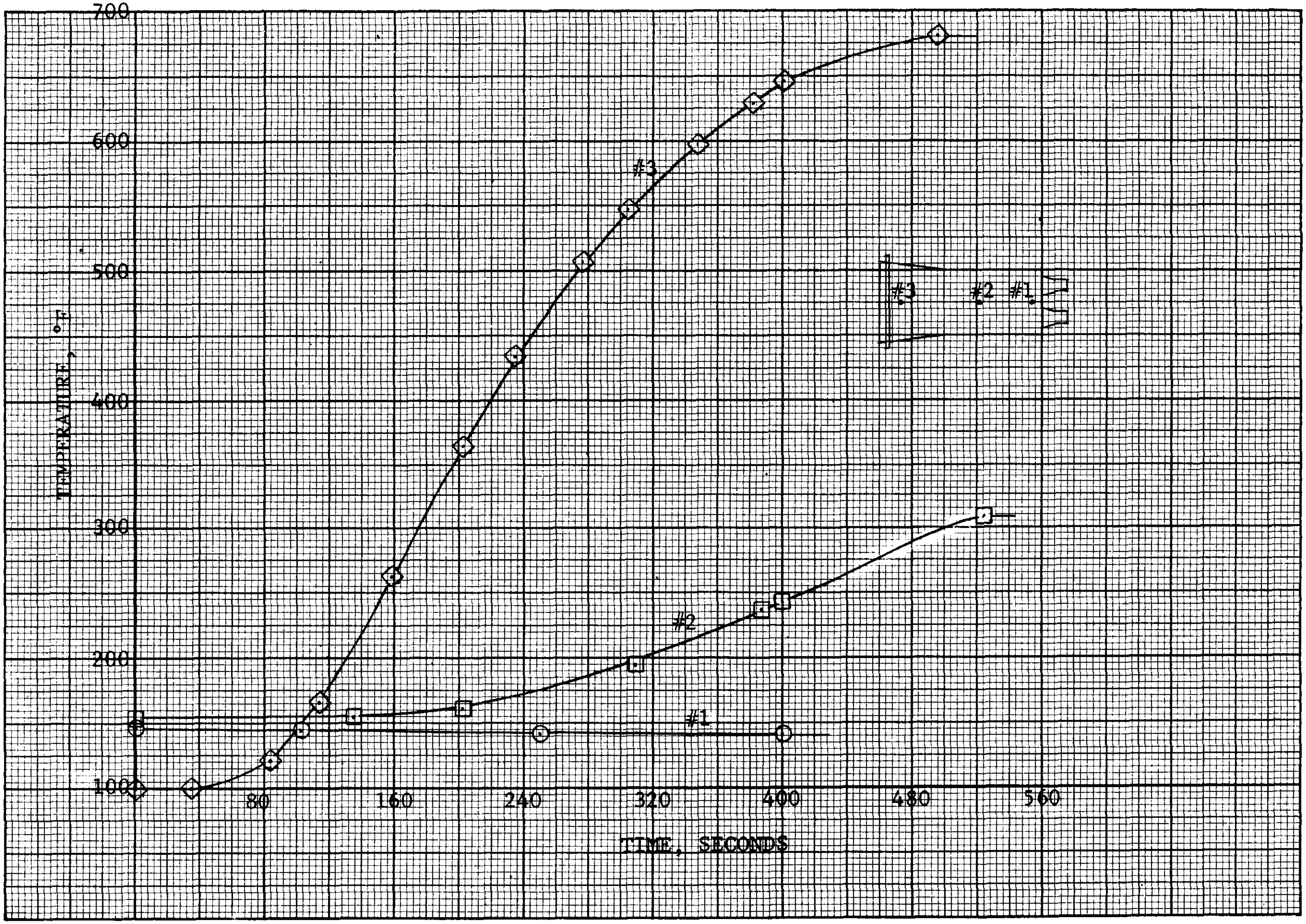


FIG 13 SKIN TEMPERATURE VERSUS TIME - TCA 1 (400 SECOND RUN)

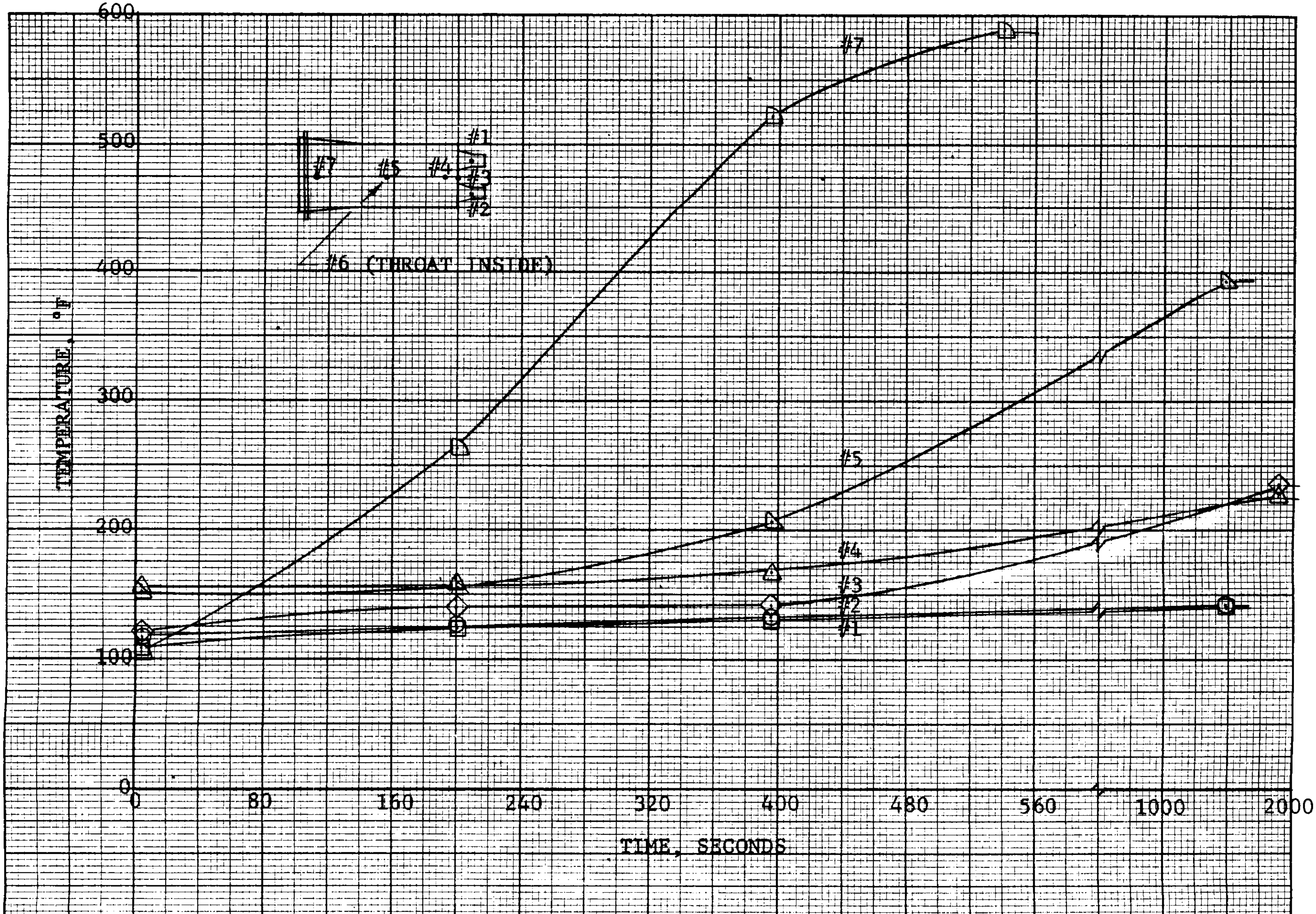


FIG 14 SKIN TEMPERATURE VERSUS TIME - TCA 2 (400 SECOND RUN, 150^0 F PRE-SOAK)

fourth duty cycle conducted on TCA 2. These measurements were taken at the nozzle exit cone next to the mounting flange. The maximum g-load experienced was 7.2 g rms at a frequency of 4700 cps in the longitudinal plane. This frequency corresponded closely to the frequency of combustion chamber pressure oscillations observed in tests conducted on a Gemini prototype engine in which the Pc transducer was close coupled. This type of information was not obtained during all Qual tests. The Pc transducer was located approximately three feet from the engine because of the heat problem and resulting transducer zero shift observed in the prototype engine firings.

Vibration measurements in the longitudinal, vertical (radial), and transverse (tangential) planes at the exit flange and trunnion mount were measured in each of the four duty cycles conducted on TCA 4. The maximum g-load (15.2 g rms, 4150 cps) occurred in the longitudinal plane at the trunnion mount. The magnitude of the vibration at the exit mounting flange was comparable to the vibration on TCA 2. Oscillograph traces of the vibrations measured on TCA 2 and a corresponding spectrum analysis are contained in FIG 15 and 16. Oscillograph traces of vibrations at the exit mounting flange and trunnion mount for TCA 4 are presented in FIG 17 and 18. Spectrum analyses for the vibrations measured on TCA 4 at the exit mounting flange and trunnion mount are presented in FIG 19 and 20. The magnitude of vibration, as depicted by the oscillograph traces, is the result of the addition of several vibration loads of different frequencies. The true g-load at each frequency was determined through a spectrum analysis using a frequency band width of 100 cps.

CONCLUSIONS FROM FIRING TESTS

The following conclusions are based upon test data and observations:

The 100 pound thrust Gemini OAMS engine adequately meets the hot firing requirements of the S-IVB mission duty cycle.

The Gemini OAMS engine has extended operational capability as evidenced by the four duty cycles conducted on two engines (approximately 2600 seconds total firing time).

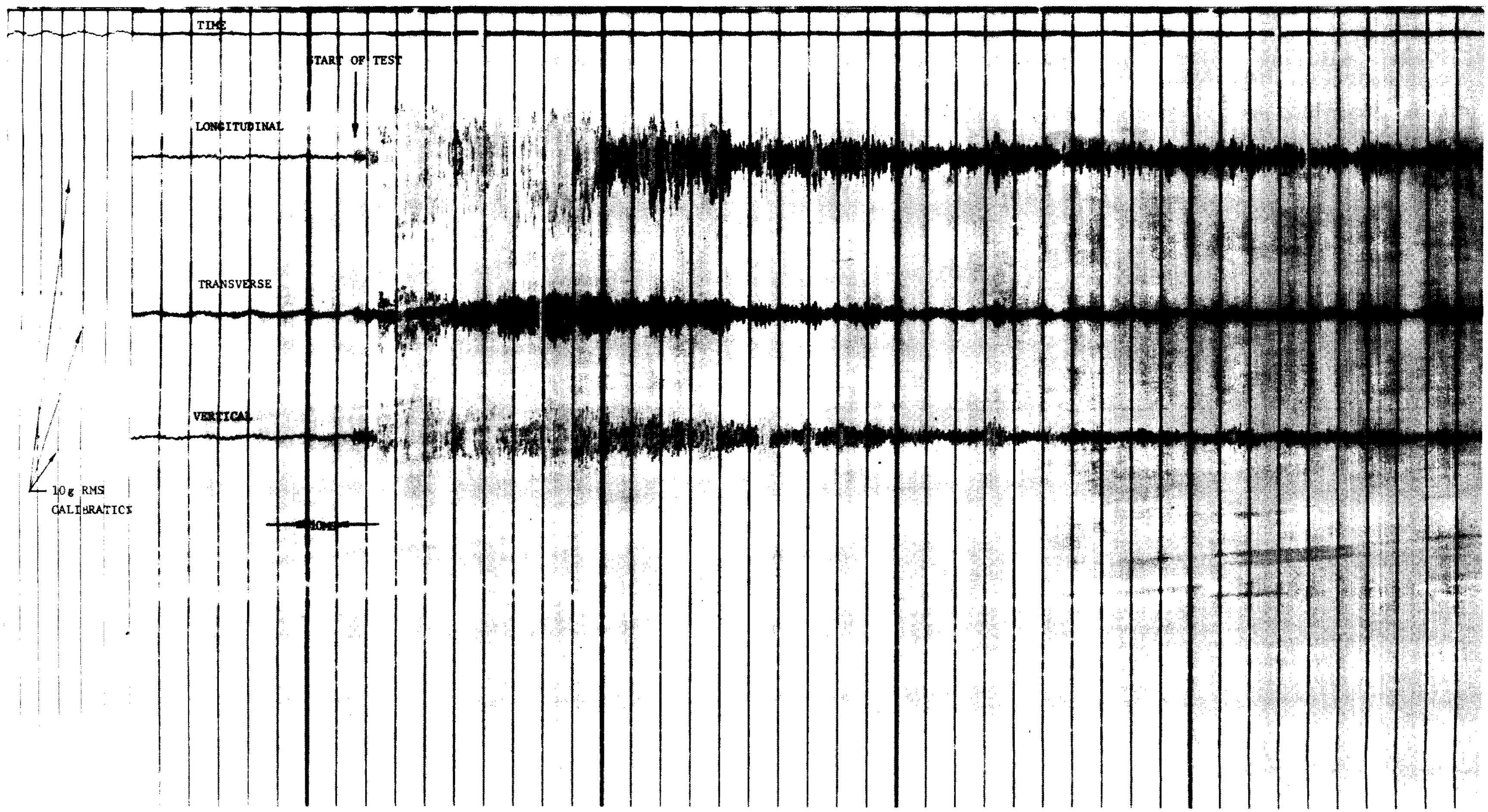


FIG 15 VIBRATION TRACES AT THE EXIT MOUNTING FLANGE ON TCA 2 - TEST C-028-89
(TYPICAL)

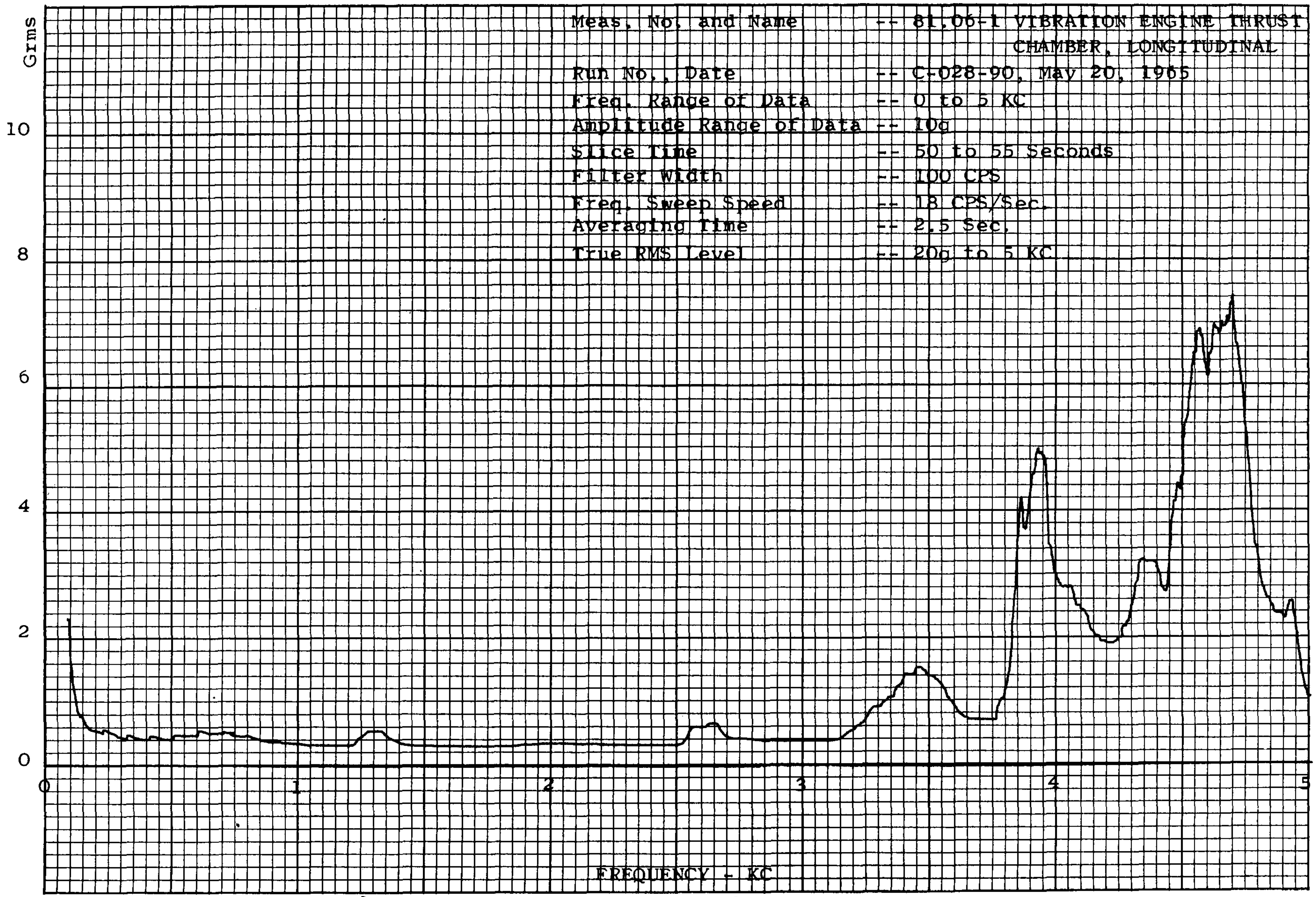


FIG 16 VIBRATION AMPLITUDE VERSUS FREQUENCY - TCA 2

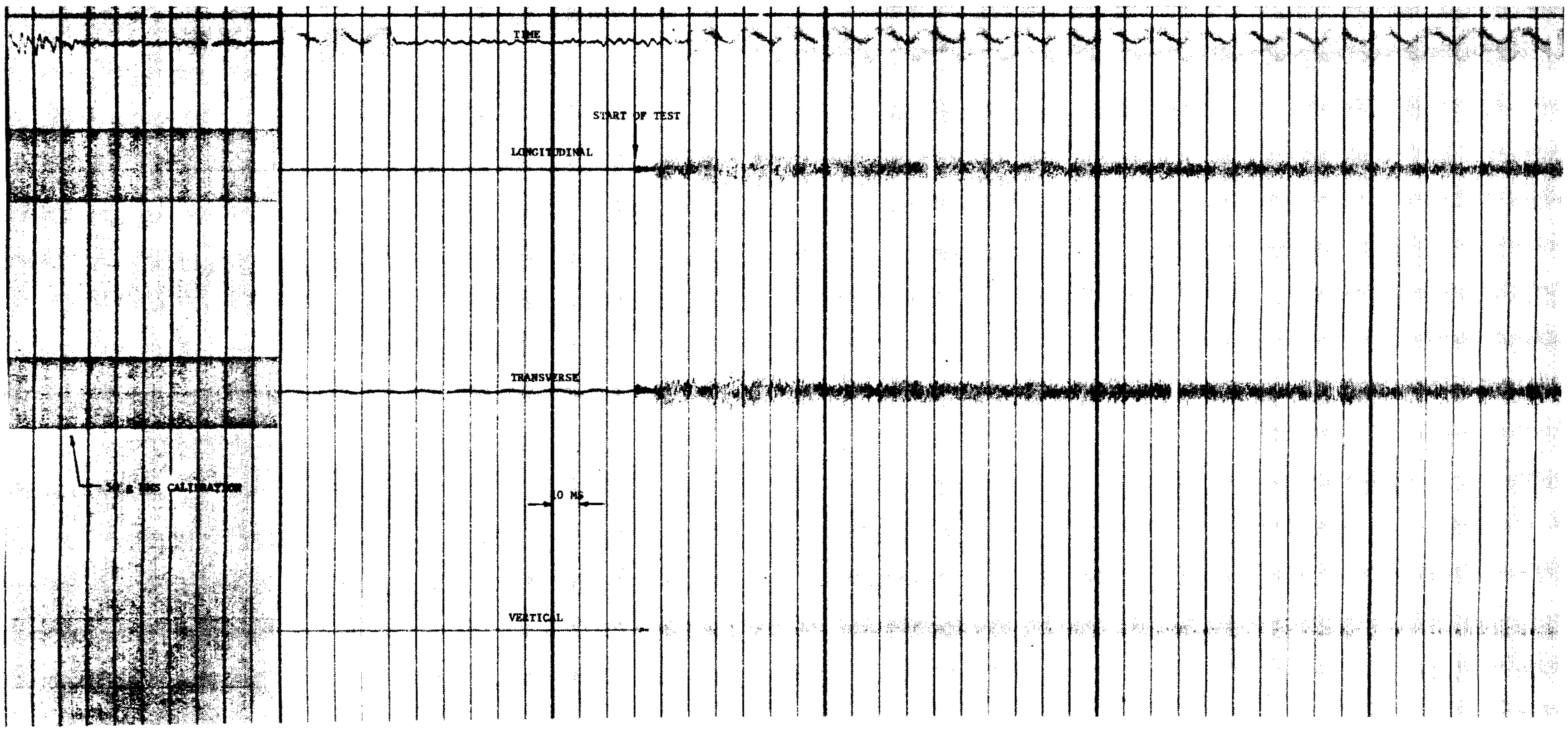


FIG 17 VIBRATION TRACES AT THE EXIT MOUNTING FLANGE ON TCA 4-TEST C - 028 - 114

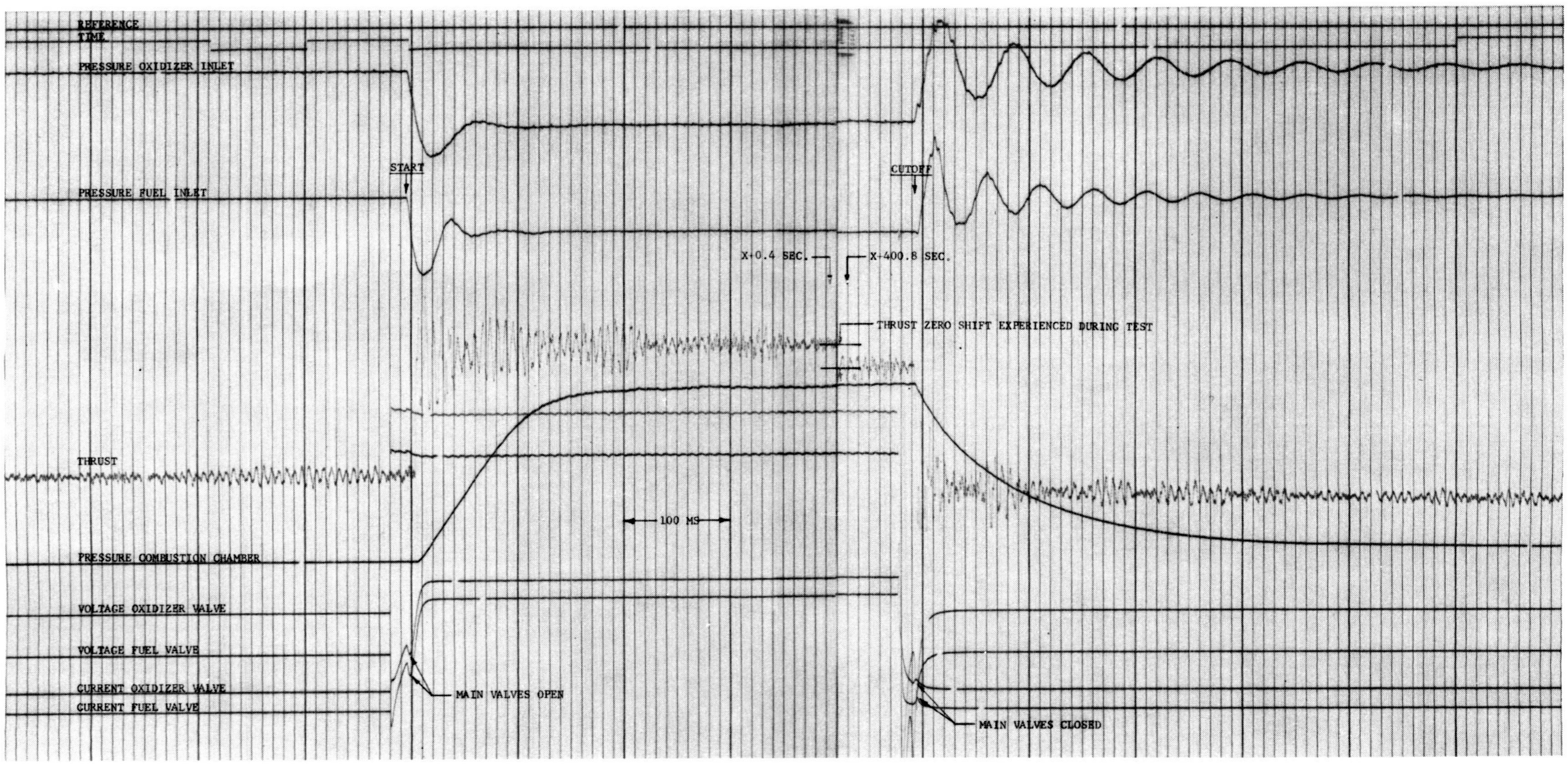


FIG 8 OSCILLOGRAPH TRACES ON TCA 4 - TEST C-028-114

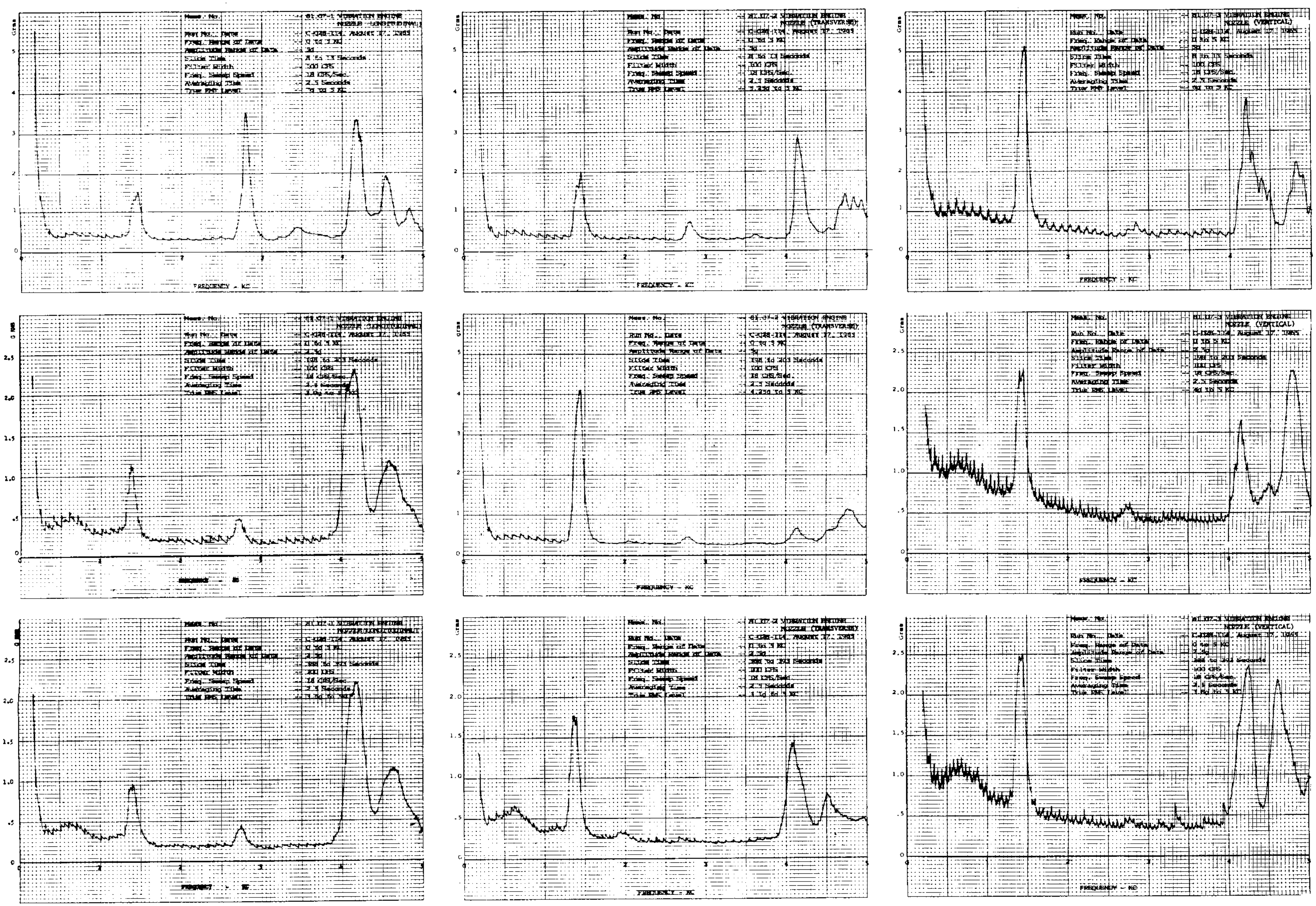


FIG 19 VIBRATION AMPLITUDE VERSUS FREQUENCY AT EXIT MOUNTING FLANGE - TCA 4

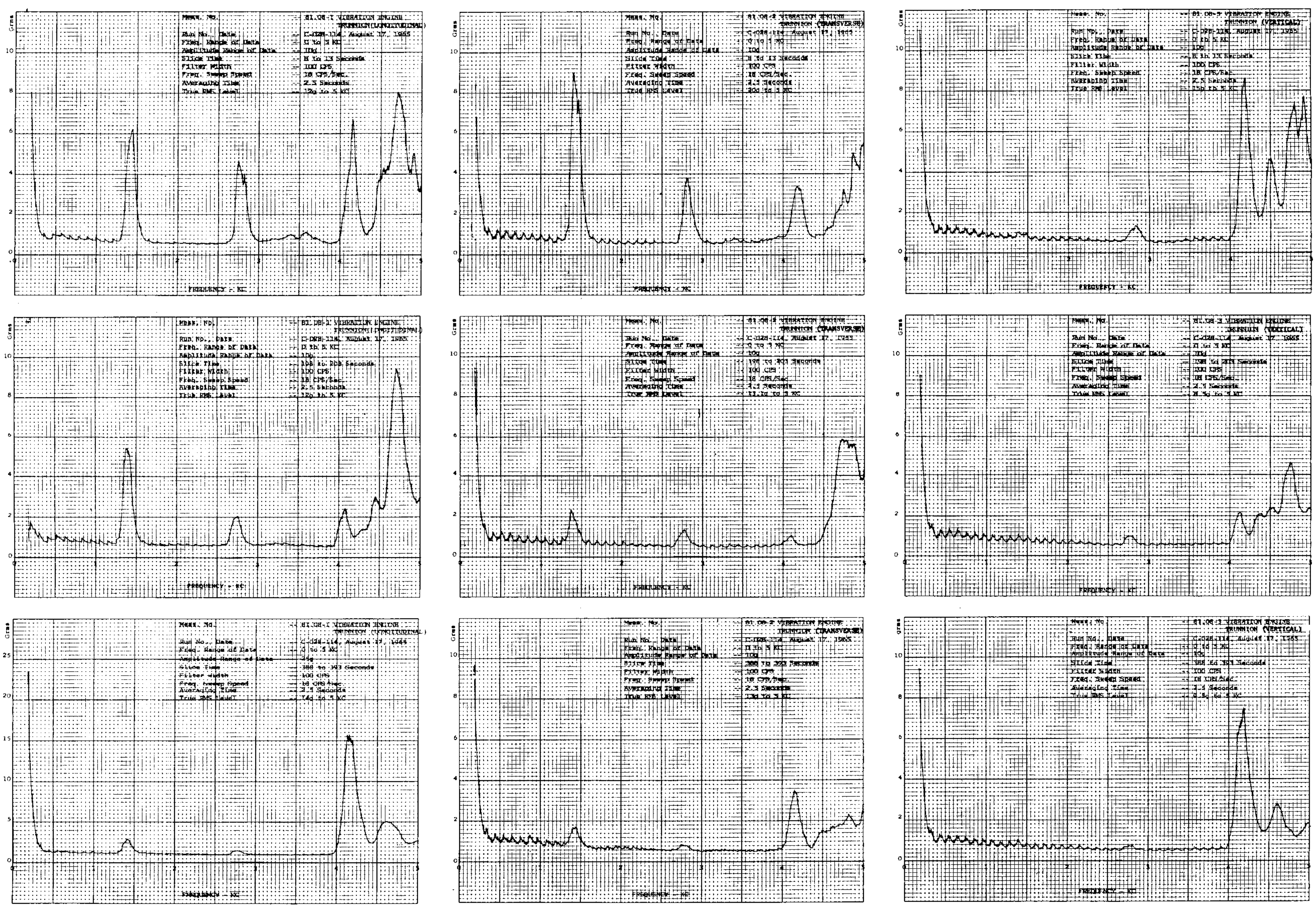


FIG 20 VIBRATION AMPLITUDE VERSUS FREQUENCY AT TRUNNION MOUNT - TCA 4

The Chamber liners that cracked on two engines did not affect their operational capabilities. It should be noted that on TCA 2, which was tested through four duty cycles with 120°F propellants, the liner did not crack. Also, the liner did not crack on TCA 4, which was tested through four duty cycles with a propellant temperature of approximately 90°F. The chamber liners cracked on TCA 1 (50°F propellants) and TCA 3 (20°F propellants).

VIBRATION/SHOCK QUALIFICATION

Vibration Test Equipment

Vibration and shock qualification of the Gemini SE-7 engine was performed on a Ling-200 shaker table. The engine and test fixture were instrumented by Endevco Model 2213M5, 2229, and 2242C accelerometers. Data was recorded on an oscillographic chart and a magnetic tape.

Vibration Requirements

Input vibration levels for the test series were based on the S-IVB stage major structural vibration levels as specified in Reference 3. Each of three orthogonal planes was excited to the following specifications:

I. Vibration Test Series

A. Sine sweep vibration

5-47 cps @ 0.031 in. D. A. displ.
47-220 cps @ 3.6 g's peak
220-295 cps @ 0.0014 in. D. A. displ.
295-2000 cps @ 6.2 g's peak

B. Random vibration (applied as one input for 12 minute duration)

20-85 @ 0.025 g^2/cps
85-280 cps @ 6.5 db/octave
280-1000 @ 0.31 g^2/cps
1000-2000 cps @ -12.0 db/octave

II. Shock Test Series - half sine wave input of 10 $\pm$ 2 milliseconds duration and 20 G's peak amplitude.

These vibration levels represented stage inputs to the attach points for the APS module and not the levels which would occur at the engine mounts. In view of this, it was necessary to vibrate the engine in a fixture that would simulate the module's reaction to stage induced vibration.

Vibration Test Fixture

The test fixture, designed and fabricated by Douglas Aircraft Company (DAC), was mock-up of the APS module's engine compartment rigidly attached to a mounting fixture at its foward end and at two simulated stage attach points on the compartment side. The engine compartment section of the module extends approximately 27 inches forward from the module aft bulkhead and contains two of the four stage-to-module attach points. The engine was mounted in the compartment along with the associated feed line plumbing, mounting bracketry, and mass models simulating the attitude control engines.

The mounting fixture was constructed of a framework of large diameter pipe and allowed the module to be bolted to the shaker head by means of three mutually perpendicular flanges, one for each of the prescribed planes of analysis. Vibration and shock inputs were controlled at the simulated vehicle attach points between the engine compartment and mounting fixture rather than at the shaker head (see FIG 21). Control from this position gave a more accurate simulation of actural vibration transfer from the vehicle to the module, but sometimes resulted in overload of the shaker equipment.

The method of installing the engine into the module was designed by DAC around the basic engine characteristics used in the Gemini. This was necessary because of the ground rule stipulation that no modifications to the SE-7 engine would be allowed since such modifications might divert the engine contractor's efforts from his primary objective - the Gemini program.

Engine support and thrust transmittal were accomplished at the two trunnion mount bosses located on either side of the engine in the injector plane. Additional engine stabilization came from the 0.020 thick stainless steel flange, butt welded to the chamber outer shell at the nozzle exit (see FIG 22). This flange was slightly contoured (48-inch radius) for the Gemini application to blend in with the capsule fairing and was designed strictly as a positioning device, not as an axial load carrying member. In the APS installation, the engine nozzle flange was bolted to a flexible diaphram ring, composed of laminated, 0.012 inch thick, stainless steel rings which was in turn bolted to the module aft bulkhead (FIG 22, Configuration 1 and FIG 24). The diaphram ring was designed to allow limited axial movement or thermal growth of the engine before exerting a restraining force, and

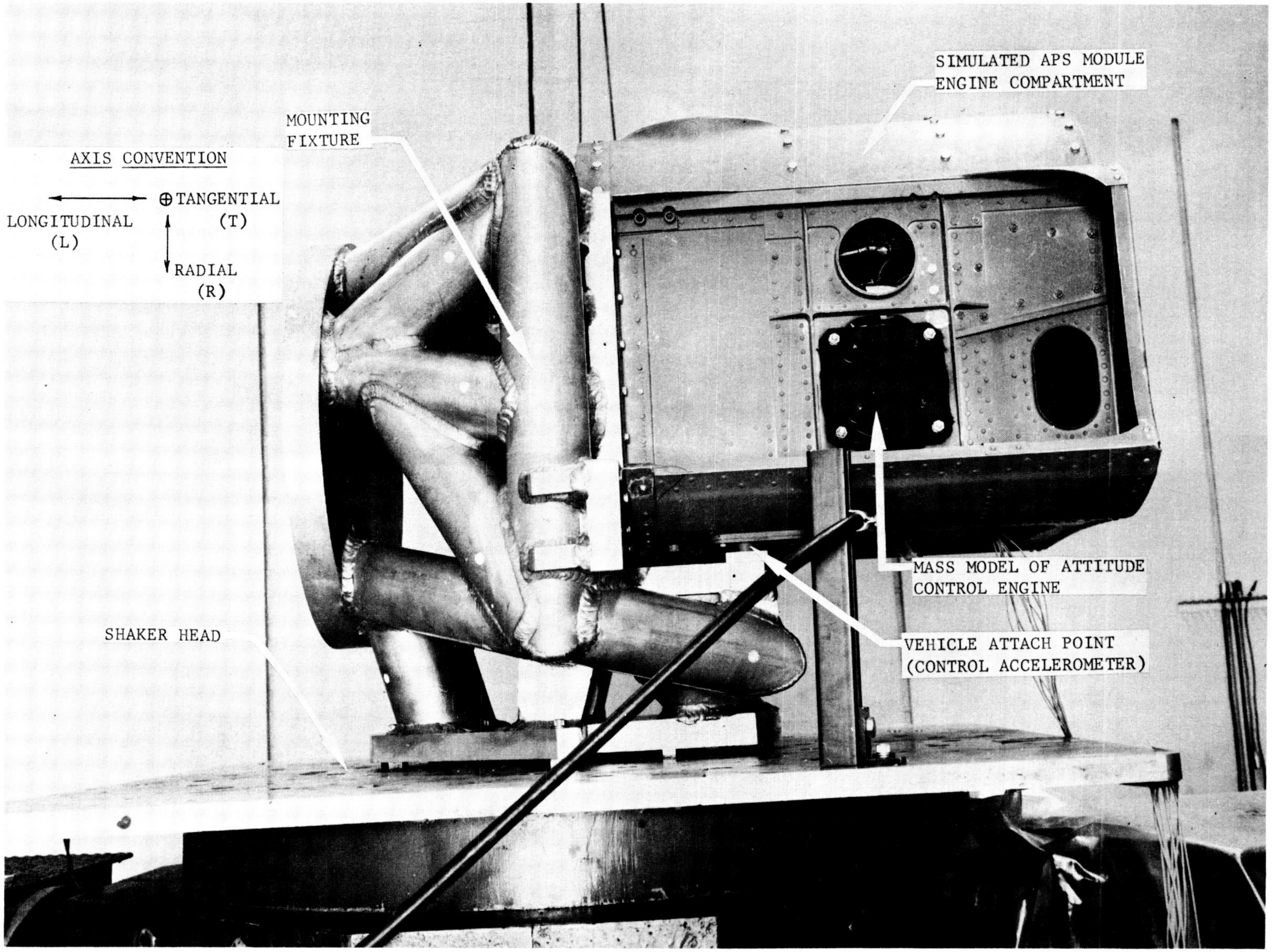


FIG 21 VIBRATION/SHOCK TEST FIXTURE MOUNTED FOR EXCITEMENT IN THE RADIAL AXIS

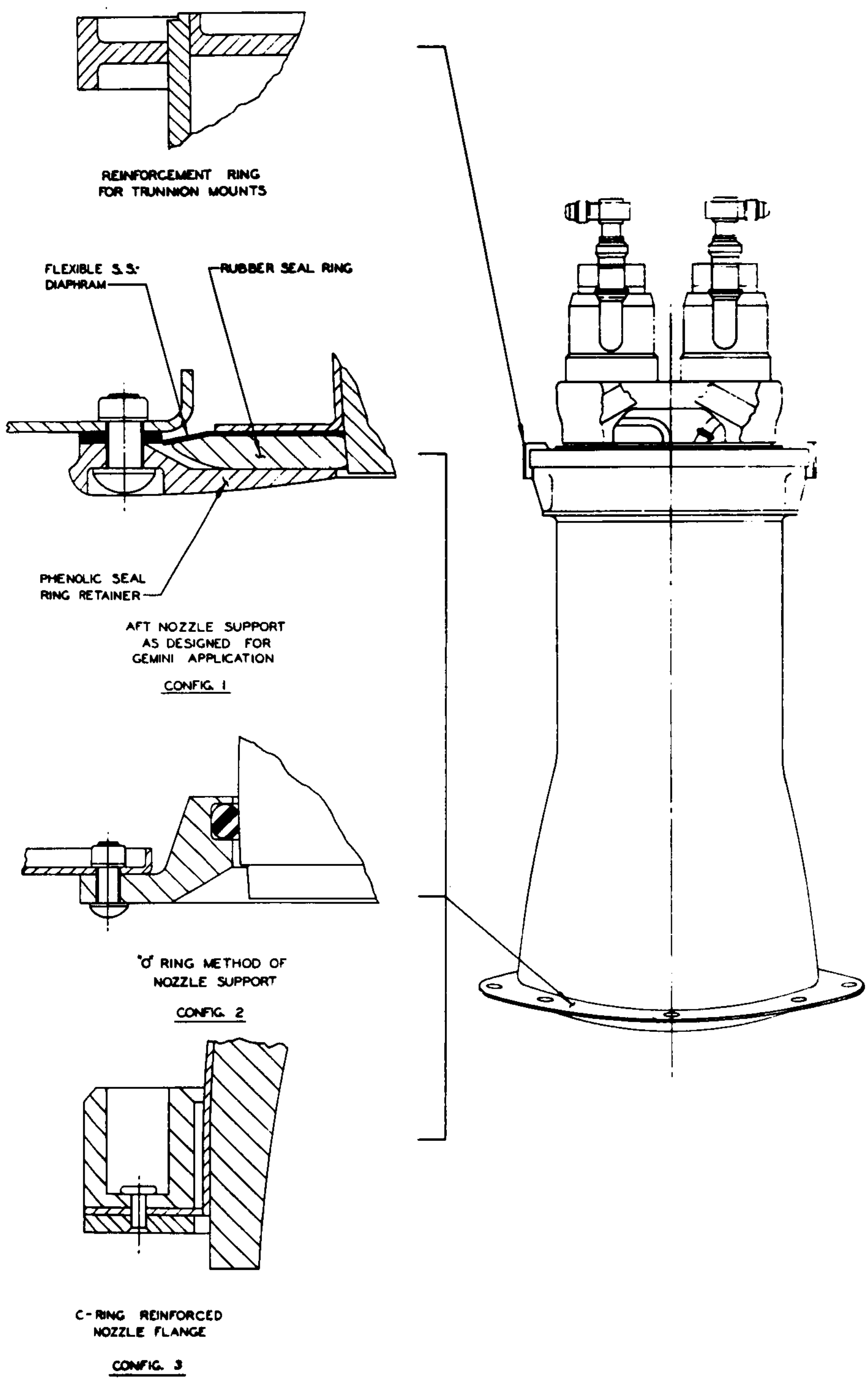


FIG 22 METHODS OF SUPPORTING AND REINFORCING SE-7 ATTACH POINTS

the lateral motion was entirely restricted. For the diaphram to function as intended, extremely tedious installation procedures were necessary. These procedures were complicated by the slight radius of the nozzle flange and the rather loose tolerances of pertinent engine and module dimensions.

Preliminary Vibration

A preliminary vibration test series was conducted in the tangential plane to check-out test fixture reaction to the specified excitation. A mass-model of the Gemini engine was installed for the preliminary test to preclude damaging the actual qualification engine (TCA 4) as a result of a failure of a test fixture or malfunction of the shaker table. Tests 1 and 2 with the mass simulated engine indicated that the shaker and test fixture were suitable for vibration testing of an actual engine.

As an additional precaution, engine TCA 3, which had already completed its hot firing demonstration for qualification, was placed in the test fixture and subjected to the vibration series in all three planes (Tests 3 thru 8). Test data for this and all succeeding tests can be found in Appendix D.

The test series was conducted with a limited visual inspection of the hardware between phases and planes of vibration. Thorough inspection was hindered by the view-obstructing hardware surrounding the engine. After vibration the engine was removed, revealing that it had been installed incorrectly by unintentionally omitting the engine compartment seal ring that was a part of the nozzle flange assembly kit (FIG 22, Configuration 1). In addition, several weld failures were discovered. The weldment joining the nozzle support flange and the nozzle outer shell had separated along approximately 120^0 of its circumference at the short side of the scarfed exit plane. Both trunnion mounts had failed at or near the weld joint to the chamber. These failures extended up to and along the burn-down weld joint between the injector body and chamber shell in the vicinity of the trunnion mounts (FIG 23). It was impossible to ascertain the plane of vibration or exact time that the various failures occured, due to the limited inspection during the tests. Data summarizing these tests is shown in Table V and FIG 28 in Appendix D.

As a result of these failures, TCA 1, which had also completed its designated hot firing portion of Qual program, was installed in the module for preliminary vibration testing to further investigate the failure

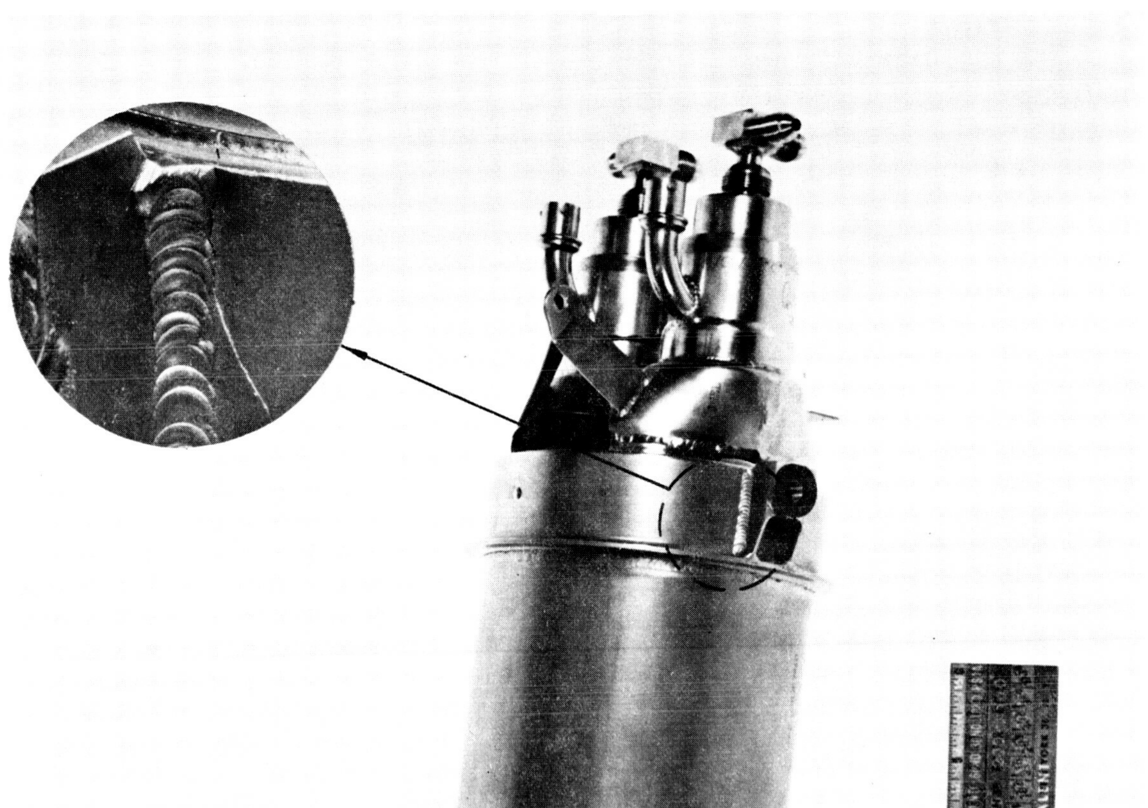


FIG 23 VIBRATION INDUCED FAILURES
AT ENGINE ATTACH POINTS

FIG 24 TCA 1 WITH REINFORCED FLANGE
FOR VIBRATION IN THE RADIAL AXIS

modes without subjecting the actual vibration qualification chamber to possible damage. In view of the results of the previous test, care was taken to correctly install the engine. Sine sweep vibration in the longitudinal plane was completed without mishap (Test 9). Random vibration in this plane (Test 10) caused the aft flange to fail in the same manner and area as had occurred on the previous engine. The engine was removed, and triangular reinforcing gussets were welded between the chamber shell and flange to repair the existing break as well as insure further flange failures were eliminated (FIG 24).

The modified chamber was subjected to the sine sweep series in the radial axis (Test 11) without visible failure. The random series (Test 12) was begun in the same plane and interrupted after 6 minutes of the specified 12 minute test at which time a faint indication of a failure was observed near one trunnion mount. At the conclusion of the full 12 minutes of test a definite failure existed in the suspected area. The burn-down weld between the injector body and chamber shell was again separated immediately behind the trunnion mounts, but only one trunnion had sustained a fracture along its side. This occurrence was identical to that of the previous case; the failure apparently propagated from the separation of the burn-down weld in the trunnion area, extending along the sides of the trunnion mounts. From this test (with the nozzle flange known to be intact), it was concluded that the flange and trunnion failures were independent. Data summarizing tests on TCA 1 are given in Table V, and Figures 29, 30, and 31, Appendix D.

Results of Preliminary Vibration Tests

As a result of data and design reviews by all parties concerned, that is NASA, Rocketdyne, and Douglas - the following observations and recommendations were made after preliminary vibration testing:

I. Since the failures thus far had occurred on engines that had already seen hot firing service, some doubt was cast on whether the failures were entirely due to vibration. The flange, which has a slight curvature for use in the Gemini application, was bolted to a flat surface during hot firing. This could have placed undue loading on the weld joint, but the position of the failures and the slight degree of flange curvature (48 in. radius) indicated otherwise. Another adverse feature of the mounting method during hot firing was the rigid connection between the nozzle support and trunnion mounts; no compensation could be made for any thermal growth of the engine during operation. The flange was retained only along a 120^0 portion during hot firing, and this portion coincided with the area of vibration failure.

II. Installation of the nozzle flange in the module aft bulkhead would require more exacting procedures so that the DAC specifications could be met. The diaphram subassembly of the nozzle flange mounting kit (FIG 24) would be fabricated from a thinner material (0.008) to increase flexibility.

III. The flange failures were caused by the combination of two separate modes of vibration. One was the breathing, or "oil canning," mode of the engine compartment aft bulkhead while the engine was rigidly retained by the trunnion mounts. The other was a very significant lateral (cross-axis) response that was induced by the module structure while it was excited in the longitudinal direction. The combination of loads from these two modes presumably cracked the weld joint in the random test.

IV. The trunnion failures were concluded to be the result of overloads sustained during the severe random vibration in the radial plane coupled with inherent design weaknesses.

V. All modifications would be confined to strengthening the engine assembly. This decision was the result of the relative complexity involved in approaching the problem through module modification. The only exception to this was the addition of a stiffening member to the aft bulkhead to reduce the amplitude of the breathing mode.

VI. TCA 3 would be repaired and subjected to one more test series of non-qualification vibration in the longitudinal plane (Tests 13 and 14) to obtain oscillation phase relationships between structural components of the engine compartment and the flange and trunnion mounts on the engine. This data aided in the stress design of the flange reinforcement and is presented in Appendix D, Table IV.

VII. TCA 2 (the only remaining engine that had not been vibrated, other than the official vibration qualification engine - TCA 4) would be returned to Rocketdyne for reinforcement modification after completing its specified hot firing qualification. Subsequent vibration of this engine would serve to prove the modifications for incorporation on the actual vibration Qual engine.

Preliminary Tests of the Rocketdyne Modified Engine

The Rocketdyne design for strengthening the trunnion areas consisted of a two-piece, "T" cross-section ring, completely around the circumference of the chamber at the trunnion mount plane. This member was welded to the chamber at the base of the "T" and to the two trunnions themselves, tieing them together (FIG 22 and 25). The nozzle flange was stiffened by the addition of a C-channel back-up ring welded to the upper (injector) side (FIG 22, Configuration 3). This ring was contoured to fit the slight curvature of the flange surface.

These reinforcements were placed on TCA 2 before it was subjected to the specified vibration series in all three planes (Tests 15 through 20). The engine was removed from the test fixture between planes of vibration for visual and dye-penetrant inspection. It was difficult to inspect the weld between the nozzle flange and chamber shell because the reinforcing C-ring obstructed the view.

In attempting to conduct the random vibration test in the final plane (tangential), the circuit breakers overloaded and initiated cutoff of the shaker table. Examination of the shaker equipment and test fixture indicated that the power amplifiers were being overloaded in the attempt to reach the vibration input levels specified. This was caused by considerable attenuation of the input levels by the mounting fixture between the shaker head and control accelerometer.

During three abortive attempts, the engine was subjected to displacements in excess of one inch at frequencies in the 70-80 cps range. This greatly exceeded the displacements observed in previous tests along the same axis and can be directly attributed to the failure of the amplification equipment to control the input levels properly. After the three unsuccessful attempts of the random test (sinusoidal had been completed without difficulty) the vibration input levels were adjusted manually so that the table would operate at a level just below the automatic cutoff limit.

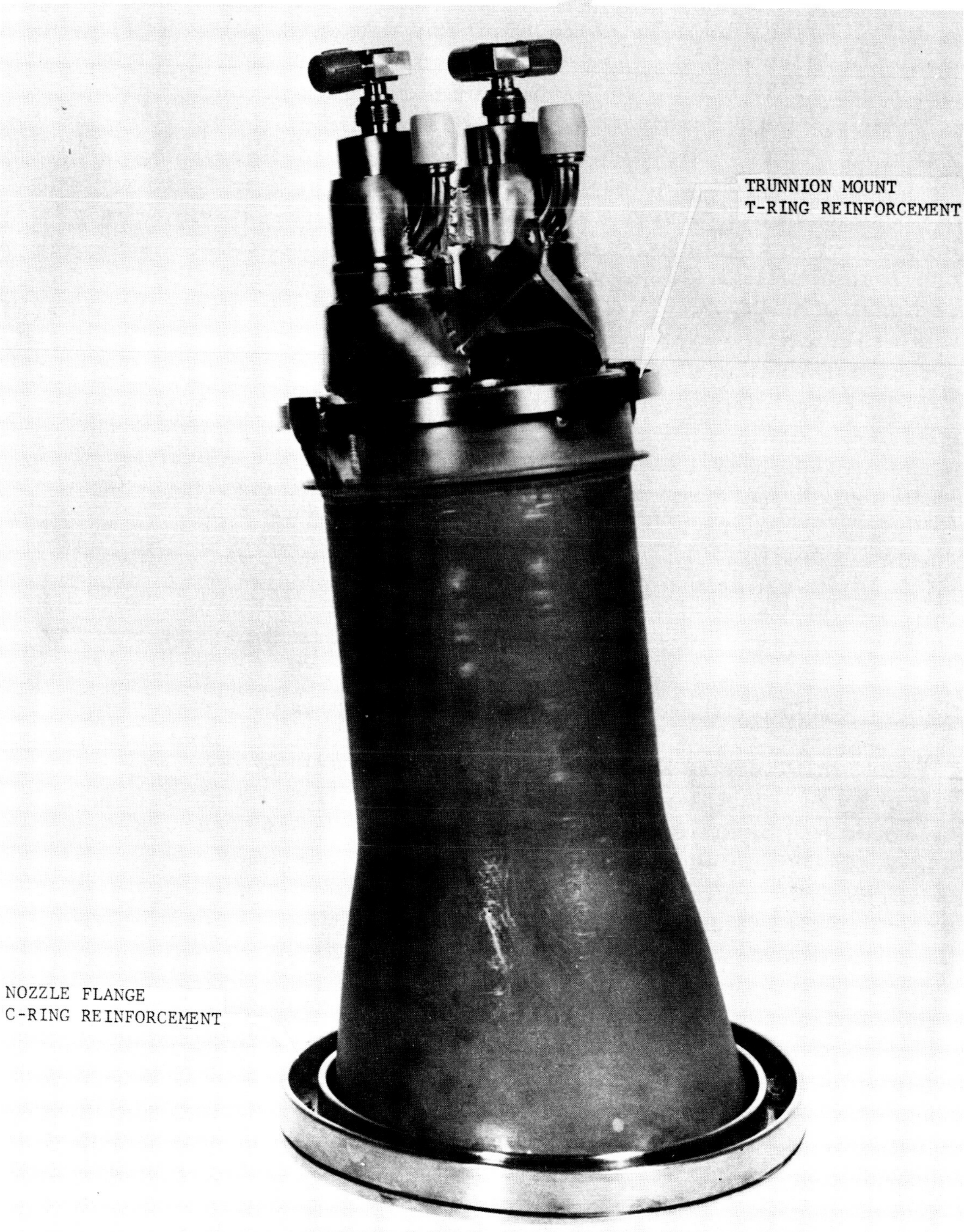


FIG 25 TRUNNION MOUNT AND NOZZLE FLANGE REINFORCEMENT FEATURES

After completion of the vibration series, the engine was removed and the C-ring flange reinforcement was detached by manually grinding away the fillet welds. This action was necessary so that the flange weldment to the nozzle shell could be thoroughly inspected. Removal of the ring was difficult, and some strain was applied to the flange weldment. The inspection disclosed a 1.5 inch failure along the weld located approximately 60^0 from the short side of the scarfed exit. Since this did not closely resemble previous failures, either in location or severeness, it was assumed to be a result of the flange overloads suffered during the abortive radial random series and/or removal of the C-ring. Close examination of the failure substantiated this assumption by indicating that the break appeared to be an overstress rather than a vibration induced fatigue fracture (See Ref. 4). Vibration test data on TCA 2 is shown in Table VIII, Appendix D.

Even though all indications pointed away from a vibration associated failure, an element of doubt was cast on the Rocketdyne flange reinforcement fix by the failure itself. The decision was made to modify the final vibration qualification engine (TCA 4) with the Rocketdyne reinforcements while an alternate method of solving the flange failure would be pursued by MSFC.

Nozzle Mounting Modifications and The MSFC Modified Engine

In addition to the failures that had occurred thus far, the difficulty of installing the nozzle support flange in the module aft bulkhead had become increasingly more evident. This problem was neither complicated nor alleviated by the Rocketdyne reinforcement features attached to the basic engine. By now it was realized that proper nozzle flange installation to the requirements set forth in the DAC installation drawings could only be realized when the flange and bulkhead planes were parallel. This condition could be obtained by extreme control of tolerances of the pertinent dimensions on both engine and module, by flexible mounting methods (that is slotted holes, sliding plate nuts, etc) or a combination of both. In modifying the final Qual engine, an additional fixture was incorporated by Rocketdyne in an effort to reduce the installation problem. A shim was attached to the opposite side of the nozzle flange from the reinforcing C-ring. This shim was contoured to fit the curvature on the flange side but offered a flat surface for attachment to the module bulkhead on the other side, thereby removing the flange contour variable.

Because of the importance of the engine installation procedure, any alternate flange reinforcement proposed by MSFC would incorporate features to relieve the problem. With this in mind, an O-ring support collar was considered as being the most efficient design. This technique was already in use at the nozzle supports for the attitude control engines of the APS module. The design involved removing the flange completely from the nozzle shell and fabricating a ring-like collar that would fit the contour of the stainless steel nozzle shell at the exit area. This collar slipped over the injector end of the chamber, and as a result of the tapering nozzle, an O-ring was compressed within a groove machined in the collar's contour-fitting surface. An integral flange was machined on the collar for supporting the unit in the module aft bulkhead (see FIG 22, Configuration 2 and FIG 26). This design provided uniform lateral support and allowed axial freedom for vibration induced motion or thermal expansion. In addition, the collar was free to swivel slightly during installation to eliminate the problem of non-parallel nozzle exit and aft bulkhead planes.

Official Qualification Tests

During the time that the final qualification engine was being modified by Rocketdyne, the O-ring nozzle support described above was designed, fabricated and tested on TCA 2, the engine with the Rocketdyne reinforcements that had just completed the test series. Since the flange C-ring had already been removed to benefit inspection, it was an easy task to manually remove the remaining flange material. The Rocketdyne trunnion reinforcement was not disturbed because it appeared to be acceptable. With TCA 2 modified as described, all three planes of the vibration test series were conducted without incident (Tests 22 through 27) and post test examination did not reveal any test hardware or engine irregularities.

As a result of the shaker equipment overloads experienced during the previous tangential plane test series, the control accelerometer was relocated from the simulated module/vehicle attach point to the shaker head during this plane of testing. This location for controlling the vibration input kept the loads transmitted to the engine far below those seen in previous tangential testing. In view of this, the plane was later repeated with the control accelerometer mounted at the module/vehicle attach point with manual control of the shaker input levels. This manner of control and the resulting vibration inputs

FIG 26 O-RING NOZZLE SUPPORT ASSEMBLY
WITH MODIFIED ENGINE FOR SAME

duplicated those seen during previous tangential testing.

It is significant to note that the trunnion reinforcement on this engine had accumulated twice the specified vibration test time without failure. Vibration data from these tests is presented in Table IX, Appendix D.

On July 28, 1965, TCA 4, complete with Rocketdyne modifications, was installed in the test fixture for initiation of the official vibration Qual test series. The contoured shim, which had been attached to the nozzle flange to facilitate installation in the module, did not appreciably affect the mounting procedure. The only failures recorded during this vibration series (Tests 28 through 33) were a sheared trunnion bolt and several sheared rivets in the module structure. These could be definitely attributed to fatigue effects of the large number of tests that had been conducted on the fixture. Post test examination indicated that the engine had achieved qualification. Vibration data from tests on TCA 4 are presented in Table X, FIG 35 and 36, Appendix D. The engine was then subjected to the comparatively mild shock series without incident. These tests officially concluded the vibration/shock phase of the qualification program.

RESULTS OF VIBRATION/SHOCK TESTS

It should be stated that the greatest limitation of the vibration/shock test program was the degree of authenticity of the test set-up in simulating actual flight hardware. The vibration levels and test fixture hardware utilized during this program are considered to be as realistic as possible in view of the funding, schedule and premature module design limitations existing at the time.

To recapitulate on the highlights of the vibration qualification, the following observations and data are presented:

I. Predictions of likely failure areas on the engine had emphasized the propellant valve assemblies which were mounted on the back surface of the injector body. These units were welded to mounting brackets which were in turn welded to the injector body (FIG 1). The cantilevered effect of the valves supended on their mounting brackets would appear to be highly susceptible to vibration failures. The weld joints of the valve supports were expected to be the most critical area, and the valves themselves were instrumented with accelerometers during the pre-qualification tests. Data from these tests indicated an insignificant amplification factor of g levels between the valves and trunnion mounts (see Table VII, Appendix D). Pressure to the valve inlets was maintained during the tests and there was never any indication of vibration induced valve leakage. Inlet fittings to the valves did break off on two of the pre-qualification engines, but these were temporary fittings of a two-piece, welded construction and were later replaced with a one-piece type of the official qualification engine and qualified successfully.

II. All failures during the pre-qualification vibration tests occurred on engines that had been previously hot fired. This fact, coupled with the method of mounting the engine for hot test, prompted serious scrutiny as to the cause of the failures. Admittedly, the mounting technique could have been, and later was, improved. But, even if the hot test history had contributed to the engine failures, the strength of the failed areas was marginal at best and required modification.

III. The engine-to-module installation procedure, as specified for the basic SE-7 engine before modification, was highly involved due to the tolerances of critical engine/module dimensions. In view of the engine failures, it was considered imperative that mounting fixtures and methods be capable of compensation for any dimensional intolerances assuring a stress-free installation and of sustaining the extreme loads of the vibration specification.

IV. The trunnion mount reinforcement modification is considered to be entirely successful, as was demonstrated by the three complete series of vibration tests that it sustained. Two of the three were accumulated on one engine, doubling the total time required for acceptable qualification.

V. Vibration levels on the engine during the official qualification (Tests 21 - 33) test series were comparable with those occurring during pre-qualification (Tests 1 - 20). Illustrations comparing the sinusoidal sweep data (odd numbered tests) for the entire program are presented in Tables XI, XII, and XIII along with the associated figures of Appendix D. Analysis of all random test data (even numbered tests) proved the results to be comparable with the sinusoidal sweep tests in both major resonant frequencies and amplitudes. Representative power spectral density curves computed from the recorded random data are presented along with all pertinent vibration data in Appendix D.

VI. Examination of data produced during the various tests indicated that the two methods of supporting the engine nozzle at the module aft bulkhead were comparably qualified with no significant differences in engine reaction to either mounting method. The C-ring reinforcement of the nozzle support flange is the officially qualified method of retaining the engine nozzle. Although this method achieved questionable results during one pre-qualification vibration test, it was successfully applied in the official qualification test. The O-ring nozzle is qualified by virtue of its endurance to the specified vibrational loading without serious effects.

CONCLUSIONS FROM VIBRATION/SHOCK TESTS

With the completion of the vibration and shock tests, two methods of supporting the engine nozzle in the module bulkhead had been qualified. In view of the installation problem, which was relieved considerably by the O-ring nozzle support technique, the recommended engine configuration is the basic SE-7 thrust chamber with the fixed flange removed from the nozzle shell and modified to include an O-ring nozzle support and trunnion mount reinforcements as qualified.

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2. Hot Firing Results of S-IVB APS Ullage Control Engine Qualification Test Program, IN-TEST-21-65, November 17, 1965.

3. Preliminary Vibration, Acoustic, and Shock Specification for Components on Saturn V Vehicle, IN-P&VE-F-63-2, Revised 9-11-64.

4. Memo R-P&VE-M-S-IVB-65-118, Analysis of S-IVB Ullage Control Motor Failure dated September 21, 1965.

APPENDIX A

STATIC TEST MEASURING PROGRAM

Appendix A-1

STATIC TEST MEASURING PROGRAM

TEST LOCATION 4750 MISSILE NO. Gemini S-IV B (100#)

SHEET OF

TEST NO. C-028

MEASUREMENT			TRANSDUCERS		RECORDING EQUIP.		
STATIC NO.	FLIGHT NO.	DESCRIPTION	NAME	CAL. RANGE	INSTR.	GROUP & NO.	REMARKS
1.21		Press. Environmental #1	CEC	0/20 mm Hg	M.V.	2-A-2	D-1QD
1.22		Press. 1st. Stage Suction	CEC	0/200mm Hg	M.V.	2-A-3	D 9QD
*1.23		Press. 2nd. Stage Suction	Dynisco	760/0mm Hg 0/-20 psig	B&F# M.V.	3-K-1	D10QD D11QD
1.24		Press. Environmental #2 (40 mm Hg Max.)	CEC	0/200mm Hg	M.V.	2-A-4	D5QD
1.27		Press. Diffuser Inlet #3	CEC	0/200mm Hg	M.V.	2-A-6	D14QD
1.29		Pressure Diffuser #2	CEC	0/200mm Hg	M.V.	2-A-7	D35QD
2.016		Press. Delta Fuel Orifice	Statham	0/25 psid	B&F #34 M.V.	3-K-11 0/15 Rg15	D3QD D4QD
2.017		Press. Delta Oxidizer Orifice	Statham	0/50 psid	B&F# 35 M.V.	3-K-12 0/5 Rg5	D17QD D18QD
3.52A		Press. Combustion Chamber (60 psig Min.)	Standard Control	-15/135 psig	M.V.	3-K-3 0/20MV	0 @ 10cs, St2@ Rg 20 D43QD, D46QD
3.52B		Press. Combustion Chamber	71377 Wiancko	-15/135 psig	Parallel M.V.	3-K-4 0 @ 10cs	D 7 QD
**3.53		Press. 1st Stage Steam Inlet	Wiancko	0/200 psig	M.V.	3L-4 (D-76-DP)	P-107-Q
**3.54		Press. 2nd Stage Steam Inlet	Wiancko	0/200 psig	M.V.	3L-6 (D-77-DP)	P-111-Q
3.55		Press. Steam Regulator Valve Inlet.	Wiancko	0/200 psig	M.V.	3L-7 (D-63-DP)	P-122-Q

NOTES:

*Write Barometric Pressure in PSIA on strip chart at beginning of each run.

**Notify test Conductor if measurement falls below 140 psig.

PREPARED Jackson DATE 5-3-65

APPROVED Merritt DATE 4-3-65

MSFC - Form 176 (June 1960)

STATIC TEST MEASURING PROGRAM

SHEET OF

TEST NO.

TEST LOCATION

MISSILE NO. Gemini S-IV B (100 #)

MEASUREMENT			TRANSDUCERS		RECORDING EQUIP.		
STATIC NO.	FLIGHT NO.	DESCRIPTION	NAME	CAL. RANGE	INSTR.	GROUP & NO.	REMARKS
4.04		Press. Fuel Inlet	Standard Control	0/250 & 0/500 psig	M.V.	2L-9	0/15 Rg15 & D-12QD 0/30 Rg30 & D-13QD
4.05		Press. Oxidizer Inlet	Standard Control	0/250 & 0/500 psig	M.V.	2L-10	0/15 Rg15 & D-25QD 0/30 Rg30 D-42QD
4.12		Press. Oxidizer Run Tank	Standard Control	0/250 & 0/500 psig	M.V. M.V.	2L-11	0/15 Rg15 & D-22QD 0/30 Rg30 D-23QD
4.13		Press. Fuel Run Tank	Standard Control	0/250 & 0/500 psig	M.V.	2L-12	0/15 Rg15 & D-2QD 0/30 Rg30 D-21QD
4.14		Press. Purge	Wiancko	0/50 psig	M.V.	3L-8	(D-49-QP) P-129-Q
15.123		Temp. Oxidizer Flowmeter	C/C Probe	32/240°F	M.V.	3M-5	0/5 MV RG 5 D-27-QD*1
15.124		Temp. Oxidizer Inlet	C/C Probe	32/240°F	M.V.	3M-2	0/5 MV RG 5 D-15-QD1
15.125		Temp. Fuel Flowmeter	C/C Probe	32/240°F	M.V.	3M-3	0/5 MV RG 5 D-27-QD2
15.126		Temp. Fuel Inlet	C/C Probe	32/240°F	M.V.	3M-4	0/5 MV RG 5 D-15-QD2
15.127		Temp. Environmental	C/C Probe	32/240°F	M.V.	3M-6	0/5 MV RG 5 D-6QD-1
15.186		Temp. 1st stage Steam Inlet	C/C Probe	32/576°F	M.V.	3M-7	0/15 RG 15 D-29QD-2
15.187		Temp. 2nd Stage Steam Inlet	C/C Probe	32/576°F	M.V.	3M-8	0/15 RG 15 D-30-QD*1
15.199		Temp. Load Cell	C/C	32/240°F	M.V.	3N-7	0/5 MV RG 5 D-47-QD*2
17.22		Temp. Diffuser #1	C/A Probe	32/120°F	M.V.	3N-1	0/2 MV RG 2 D-32-QD*2

NOTES:

PREPARED	APPROVED
DATE	DATE

MSFC - Form 176 (June 1960)

Appendix A-3

STATIC TEST MEASURING PROGRAM

SHEET ____ OF ____

TEST NO. ____

TEST LOCATION ____ MISSILE NO. Gemini S-IV B (100#)

MEASUREMENT			TRANSDUCERS		RECORDING EQUIP.		
STATIC NO.	FLIGHT NO.	DESCRIPTION	NAME	CAL. RANGE	INSTR.	GROUP & NO.	REMARKS
17.23		Temp. Diffuser #2	C/A Probe	32/120°F	M.V.	3N-2	0/2 MV RG 2 D-33-QD*1
17.24		Temp. Diffuser #3	C/A Probe	32/120°F	M.V.	3N-3	0/2 MV RG 2 D-33-QD*2
17.25		(Max. 500°F for 4 sec) Temp. Isolation Valve Inlet	C/A Probe	32/1330°F	M.V.	3N-4	0/30 MV RG30 D-34-QD*1
17.43		Temp. Engine #1	C/A	32/251°F	M.V.	3N-5	0/5 RG 5 D-28-QD*1
17.44		Temp. Engine #2	C/A	32/251°F	M.V.	3N-6	0/5 RG 5 D-28-QD-2
17.45		Temp. Engine #3	C/A	32/251°F	M.V.	3N-7	0/5 RG 5 D-31QD-1
17.46		Temp. Engine #4 (Max 650°F)	C/A	32/692°F	M.V.	3N-8	0/15 RG 15 D-31-QD-2
17.47		Temp. Engine #5 (Max 650°F)	C/A	32/692°F	M.V.	3N-9	0/15 RG 15 D-32-QD-1
17.48		Temp. Oxidizer Run Tank	C/C	32/240°F	M.V.	3M-11	0/5 RG 5 D-24-QD-1
17.49		Temp. Fuel Run Tank	C/C	32/240°F	M.V.	3M-12	0/5 RG 5 D-24-QD-2
17.50		Temp. Engine #6	C/A	32/251°F	M.V.	3N-10	0/5 RG 5 D-29QD-1
17.51		Temp. Engine #7	C/A	32/692°F	M.V.	3N-11	0/15 RG 15 D-48QD-1
22.07		Flow Oxidizer #1	Fisher-Porter 579890	0/800 cps 0/.27#/sec	Parallel M.V.	3-D-5	D-36-QD
22.04		Flow Oxidizer #2	S-530596 Cox 3147	0/1600 cps 0/.285#/sec	Parallel M.V.	3-C-5	D-40-QD
22.05		Flow Fuel #1	Fisher-Porter 579768	0/800 cps 0/.16#/sec	Parallel M.V.	3-K-5	D-41-QD
22.08		Flow Fuel #2	Cox 3145	0/1600 cps 0/.18#/sec	Parallel M.V.	3-L-5	D-19-QD

NOTES:

PREPARED	APPROVED
DATE	DATE

MSFC - Form 176 (June 1969)

Appendix A-4

STATIC TEST MEASURING PROGRAM

TEST LOCATION ______________ MISSILE NO. Gemini S-IV B (100#)

SHEET ____ OF ____

TEST NO. ____

MEASUREMENT			TRANSDUCERS		RECORDING EQUIP.		
STATIC NO.	FLIGHT NO.	DESCRIPTION	NAME	CAL. RANGE	INSTR.	GROUP & NO.	REMARKS
45.03A		Thrust (55 lbs. Min.)	SN 030010 Flex-cell	0/100 lbs.	M.V.	IE-5	D-44-QD
53.52		Press. Combustion Chamber	71377 Wiancko	-15/135 psig	Parallel Osc. 324	29	
54.04		Press. Fuel Inlet	36259 Wiancko	0/500 psig	Osc. 324	29	P-102Q
54.05		Press. Oxidizer Inlet	18910 Wiancko	0/500 psig	Osc. 324	29	P-103Q
95.03		Thrust	SN030010 Flex-cell	0/100 lbs.	Parallel Osc. 323	29	D-37-QD
96.06		Oxidizer Valve Current	0/10 MV	0/1 AMP	Osc. 344	29	D-38-QD
96.07		Fuel Valve Current	0/10 MV	0/1 AMP	Osc. 344	29	D-39-QD
96.08		Oxidizer Valve Voltage		0/28 VDC	Osc. 323	29	D-45-QD
96.09		Fuel Valve Voltage		0/28 VDC	Osc. 323	29	D-16-QD
72.07		Flow Oxidizer #1	Fisher-Porter [illegible]	0/800 cps 0/.27#/sec	Tape	1200	D-36-QD
72.04		Flow Oxidizer #2	S-530596 Cox 3147	0/1600 cps 0/.285#/sec	Tape	1200	D-40-QD
72.05		Flow Fuel #1	Fisher-Porter 579768	0/800 cps 0/.16#/sec	Tape	1200	D-41-QD
72.08		Flow Fuel #2	Cox 3145	0/1600 cps 0/.18#/sec	Tape	1200	D-19-QD

NOTES:

PREPARED ____ DATE ____

APPROVED ____ DATE ____

MSFC - Form 176 (June 1960)

APPENDIX B

TYPICAL TEST PROCEDURE

1. Install engine and complete leak check and visual inspection.

2. Start mechanical vacuum pump and evacuate test cell.

3. Begin temperature conditioning engine and/or propellants when required.

4. Perform pretest propellant bleeds to expel gas from system and to check flowmeter operation.

5. Pressurize propellant tanks to desired values.

6. Start steam ejector and achieve first stage suction pressure of 3 mm Hg.

7. Open altitude chamber isolation valve and achieve altitude chamber pressure of 3 mm Hg.

8. Perform final propellant bleeds (under tank run pressures) to obtain desired propellant inlet temperatures.

9. Hot fire engine.

NOTE:

On firing command, the exhaust cooling (water) valve, which controlled the water used to cool the exhaust gases passing through the isolation valve, started open. The "open" signal from this valve triggered the main engine valves open, thus starting the engine firing. A pre-cutoff command, which closed the exhaust gas cooling valve and opened the water purge valve, was given five seconds then "picked up" and closed the main engine valves in five seconds. This firing sequence resulted in the cooling water flowing into the diffuser duct approximately one second after engine ignition and ceasing to flow approximately one second prior to engine cutoff. Thus the engine exhaust vaporized the water spray and eliminated the possibility of any water getting into the engine.

10. CLOSE isolation valve, turn off steam ejector, and hold at altitude with mechanical vacuum pump.

11. Prepare for next hot firing.

12. Upon completion of each duty cycle, remove engine diffuser and inspect engine.

APPENDIX C

GEMINI SE-7 ENGINE HOT FIRING DATA

Qual. Engine No. 1 (S/N 4070490)	Firing No. 1 Test C-028-36, 10 sec S/T		Firing No. 2 Test C-028-37, 10 sec S/T		Firing No. 3 Test C-028-38, 10 sec S/T		Firing No. 4 Test C-028-39, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.44	0.	14.42	0.	14.40	0.	14.39	0.
Environmental Pressure, PSIA	.1006	0.	.0997	0.	.1055	0.	.1120	0.
Thrust, lbs	69.5	71.3	69.1	70.6	69.1	71.5	68.3	71.1
Chamber Pressure, PSIA	100.24	100.52	99.72	99.67	99.40	100.46	99.49	100.66
Mixture Ratio, O/F	1.270	1.270	1.270	1.270	1.270	1.260	1.260	1.250
Specific Impulse, sec.	266.8	273.0	265.7	272.0	266.2	272.0	262.6	270.0
Characteristic Velocity (C*), ft/sec.	4897	4893	4879	4874	4872	4863	4867	4862
Thrust Coefficient (Cf)	1.75	1.79	1.75	1.79	1.76	1.80	1.74	1.79
Oxidizer Flowrate, lbs/sec.	.1457	.1460	.1455	.1454	.1451	.1463	.1449	.1465
Fuel Flowrate, lbs/sec.	.1148	.1153	.1146	.1148	.1145	.1165	.1152	.1169
Oxidizer Density, lb/ft^3	91.69	89.85	91.61	89.85	91.38	89.85	91.30	89.85
Fuel Density, lb/ft^3	55.51	54.66	55.48	54.66	55.42	54.66	55.39	54.66
Oxidizer Tank Pressure, PSIA	240.44		241.42		240.90		239.89	
Oxidizer Inlet Pressure, PSIA	192.44	195.00	193.42	195.00	190.90	195.00	190.39	195.00
Fuel Tank Pressure, PSIA	214.94		214.92		212.40		213.89	
Fuel Inlet Pressure, PSIA	192.44	195.00	193.42	195.00	189.40	195.00	189.89	195.00
Oxidizer Orifice Diameter, in.	.07950		.07950		.07950		.07950	
Fuel Orifice Diameter, in.	.08300		.08300		.08300		.08300	
Chamber Throat Diameter, in.	.7095		.7095		.7095		.7095	

Qual. Engine No. 1 (S/N 4070490)	Firing No. 1 Test C-028-36, 10 sec S/T		Firing No. 2 Test C-028-37, 10 sec S/T		Firing No. 3 Test C-028-38, 10 sec S/T		Firing No. 4 Test C-028-39, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.441		4.441		4.441		4.441	
Chamber Throat Area, sq. in.	.3954		.3954		.3954		.3954	
Chamber Exit Area, sq. in.	15.490		15.490		15.490		15.490	
Local Ambient Temperature, °F	51		58		65		65	
Environmental Temperature, °F	51		66		73		86	
Oxidizer Inlet Temperature, °F	50	70	51	70	54	70	55	70
Fuel Inlet Temperature, °F	50	70	51	70	53	70	54	70
Oxidizer Flowmeter Temperature, °F	50	70	51	70	54	70	55	70
Fuel Flowmeter Temperature, °F	50	70	51	70	53	70	54	70
Engine Temperature	Amb.		Amb.		Amb.		Amb.	
Oxidizer Valve Voltage, Volts	26.1		26.3		26.4		26.5	
Oxidizer Valve Current, Amperes	.63		.59		.58		.585	
Fuel Valve Voltage, Volts	26.1		26.0		26.3		26.0	
Fuel Valve Current, Amperes	.71		.71		.65		.655	

Qual. Engine No. 2 (S/N 4071853) First Duty Cycle	Firing No. 1 Test C-028-73, 65 sec S/T		Firing No. 2 Test C-028-74, 35 sec S/T		Firing No. 3 Test C-028-75, 200 sec S/T		Firing No. 4 Test C-028-76, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.51	0	14.49	0	14.47	0	14.47	0
Environmental Pressure, PSIA	.1050	0	.1030	0	.1060	0	.1010	0
Thrust, lbs	(69.0)		(69.1)		(69.6)		(66.8)	
Chamber Pressure, PSIA	99.70	101.79	99.88	100.09	100.57	98.80	96.47	98.78
Mixture Ratio, O/F	1.180	1.200	1.150	1.130	1.195	1.120	1.120	1.100
Specific Impulse, sec.	(260.1)		(266.5)		(267.3)		(267.4)	
Characteristic Velocity (C*), ft/sec.	4799	4813	4919	4903	4933	4867	4935	4913
Thrust Coefficient (Cf)	(1.75)		(1.75)		(1.75)		(1.75)	
Oxidizer Flowrate, lbs/sec.	.1439	.1473	.1387	.1384	.1418	.1371	.1322	.1346
Fuel Flowrate, lbs/sec.	.1214	.1228	.1206	.1224	.1186	.1223	.1176	.1221
Oxidizer Density, lb/ft^3	84.55	89.85	84.77	89.85	86.20	89.85	84.35	89.85
Fuel Density, lb/ft^3	52.41	54.66	52.58	54.66	52.85	54.66	51.92	54.66
Oxidizer Tank Pressure, PSIA	243.51		240.29		246.97		236.97	
Oxidizer Inlet Pressure, PSIA	194.71	195.00	200.69	195.00	207.67	195.00	195.27	195.00
Fuel Tank Pressure, PSIA	221.01		220.99		219.47		216.97	
Fuel Inlet Pressure, PSIA	195.51	195.00	195.99	195.00	194.47	195.00	190.47	195.00
Oxidizer Orifice Diameter, in.	.07840		.07840		.07840		.07840	
Fuel Orifice Diameter, in.	.08240		.08240		.08240		.08240	
Chamber Throat Diameter, in.	.7110		.7110		.7110		.7110	

Qual. Engine No. 2 (S/N 4071853) First Duty Cycle	Firing No. 1 Test C-028-073, 65 sec S/T		Firing No. 2 Test C-028-74, 35 sec S/T		Firing No. 3 Test C-028-75, 200 sec S/T		Firing No. 4 Test C-028-76, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	90		91		90		90	
Environmental Temperature, °F	91.0		89.8		89.8		93.2	
Oxidizer Inlet Temperature, °F	136.4	70	126.0	70	113.0	70	112.5	70
Fuel Inlet Temperature, °F	145.0	70	131.2	70	125.0	70	136.5	70
Oxidizer Flowmeter Temperature, °F	140.5	70	131.5	70	115.0	70	136.2	70
Fuel Flowmeter Temperature, °F	146.5	70	133.0	70	127.0	70	152.2	70
Engine Temperature	150^{+} °F		150^{+} °F		150^{+} °F		150^{+} °F	
Oxidizer Valve Voltage, Volts	26.6		26.6		26.7		26.6	
Oxidizer Valve Current, Amperes	.57		.57		.56		.55	
Fuel Valve Voltage, Volts	26.5		26.6		26.6		26.6	
Fuel Valve Current, Amperes	.61		.62		.61		.59	

Note: Calculated data shown in parentheses.

Qual. Engine No. 2 (S/N 4071853) Second Duty Cycle	Firing No. 1 Test C-028-78, 65 sec S/T		Firing No. 2 Test C-028-79, 35 sec S/T		Firing No. 3 Test C-028-80, 200 sec S/T		Firing No. 4 Test C-028-81, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.49	0	14.46	0	14.45	0	14.45	0
Environmental Pressure, PSIA	.1140	0	.1280	0	.1440	0	.1270	0
Thrust, lbs	(69.0)		(69.1)		(68.5)		(67.2)	
Chamber Pressure, PSIA	99.69	101.15	99.81	101.05	98.95	98.52	97.05	97.86
Mixture Ratio, O/F	1.190	1.200	1.210	1.190	1.180	1.110	1.130	1.120
Specific Impulse, sec.	(260.0)		(261.1)		(268.2)		(261.9)	
Characteristic Velocity (C*), ft/sec.	4801	4807	4818	4804	4946	4881	4833	4829
Thrust Coefficient (Cf)	(1.75)		(1.75)		(1.75)		(1.75)	
Oxidizer Flowrate, lbs/sec.	.1442	.1464	.1449	.1461	.1381	.1355	.1360	.1369
Fuel Flowrate, lbs/sec.	.1212	.1224	.1198	.1227	.1173	.1223	.1206	.1220
Oxidizer Density, lb/ft^3	85.28	89.85	84.47	89.85	84.20	89.85	85.21	89.85
Fuel Density, lb/ft^3	52.64	54.66	52.41	54.66	52.23	54.66	52.66	54.66
Oxidizer Tank Pressure, PSIA	239.49		244.26		244.05		237.45	
Oxidizer Inlet Pressure, PSIA	195.49	195.00	198.06	195.00	205.65	195.00	198.05	195.00
Fuel Tank Pressure, PSIA	222.49		220.26		213.25		222.45	
Fuel Inlet Pressure, PSIA	195.39	195.00	193.46	195.00	191.95	195.00	195.75	195.00
Oxidizer Orifice Diameter, in.	.07840		.07840		.07840		.07840	
Fuel Orifice Diameter, in.	.08240		.08240		.08240		.08240	
Chamber Throat Diameter, in.	.7110		.7110		.7110		.7110	

Qual. Engine No. 2 (S/N 4071853) Second Duty Cycle	Firing No. 1 Test C-028-78, 65 sec S/T		Firing No. 2 Test C-028-79, 35 sec S/T		Firing No. 3 Test C-028-80, 200 sec S/T		Firing No. 4 Test C-028-81, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	87		88		90		90	
Environmental Temperature, °F	88.3		87.2		89.6		90.3	
Oxidizer Inlet Temperature, °F	124.0	70	129.0	70	137.6	70	118.5	70
Fuel Inlet Temperature, °F	130.0	70	136.1	70	142.3	70	127.5	70
Oxidizer Flowmeter Temperature, °F	125.7	70	134.9	70	137.9	70	126.5	70
Fuel Flowmeter Temperature, °F	131.5	70	138.1	70	143.4	70	130.9	70
Engine Temperature	150^{+} °F		150^{+} °F		150^{+} °F		150^{+} °F	
Oxidizer Valve Voltage, Volts	27.0		26.7		26.5		26.5	
Oxidizer Valve Current, Amperes	.558		.57		.565		.540	
Fuel Valve Voltage, Volts	26.6		26.4		26.2		26.3	
Fuel Valve Current, Amperes	.610		.56		.620		.589	

Note: Calculated data shown in parentheses.

Qual. Engine No. 2 (S/N 4071853) Third Duty Cycle	Firing No. 1 Test C-028-83, 65 sec S/T		Firing No. 2 Test C-028-84, 35 sec S/T		Firing No. 3 Test C-028-85, 200 sec S/T		Firing No. 4 Test C-028-86, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.47	0	14.46	0	14.44	0	14.44	0
Environmental Pressure, PSIA	.1130	0	.1160	0	.1180	0	.1110	0
Thrust, lbs	(67.9)		(67.9)		(66.2)		(66.2)	
Chamber Pressure, PSIA	98.12	99.81	98.11	100.61	95.64	97.50	95.54	97.66
Mixture Ratio, O/F	1.165	1.200	1.180	1.230	1.100	1.120	1.090	1.060
Specific Impulse, sec.	(258.6)		(260.7)		(263.4)		(264.9)	
Characteristic Velocity (C*), ft/sec.	4776	4808	4815	4854	4866	4889	4889	4863
Thrust Coefficient (Cf)	(1.75)		(1.75)		(1.75)		(1.75)	
Oxidizer Flowrate, lbs/sec.	.1413	.1449	.1411	.1461	.1316	.1347	.1302	.1323
Fuel Flowrate, lbs/sec.	.1213	.1204	.1194	.1187	.1197	.1200	.1197	.1243
Oxidizer Density, lb/ft^3	85.36	89.85	85.09	89.85	85.50	89.85	84.97	89.85
Fuel Density, lb/ft^3	52.73	54.66	52.95	54.66	52.75	54.66	52.53	54.66
Oxidizer Tank Pressure, PSIA	240.47		240.46		234.24		236.24	
Oxidizer Inlet Pressure, PSIA	193.47	195.00	191.06	195.00	193.44	195.00	195.24	195.00
Fuel Tank Pressure, PSIA	223.27		220.26		220.24		218.44	
Fuel Inlet Pressure, PSIA	198.27	195.00	196.66	195.00	196.04	195.00	189.44	195.00
Oxidizer Orifice Diameter, in.	.07840		.07840		.07840		.07840	
Fuel Orifice Diameter, in.	.08240		.08240		.08240		.08240	
Chamber Throat Diameter, in.	.7110		.7110		.7110		.7110	

Qual. Engine No. 2 (S/N 4071853) Third Duty Cycle	Firing No. 1 Test C-028-83, 65 sec S/T		Firing No. 2 Test C-028-84, 35 sec S/T		Firing No. 3 Test C-028-85, 200 sec S/T		Firing No. 4 Test C-028-86, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	80		82		83		82	
Environmental Temperature, °F	89.6		84		88.4		91.9	
Oxidizer Inlet Temperature, °F	120.0	70	115.0	70	123.9	70	116.1	70
Fuel Inlet Temperature, °F	127.9	70	118.1	70	128.1	70	128.8	70
Oxidizer Flowmeter Temperature, °F	124.8	70	127.8	70	123.1	70	129.2	70
Fuel Flowmeter Temperature, °F	128.7	70	122.1	70	128.1	70	134.5	70
Engine Temperature								
Oxidizer Valve Voltage, Volts	26.2		26.0		26.1		26.4	
Oxidizer Valve Current, Amperes	.58		.57		.56		.53	
Fuel Valve Voltage, Volts	26.0		26.0		26.1		26.2	
Fuel Valve Current, Amperes	.60		.60		.58		.57	

Note: Calculated data shown in parentheses.

Qual. Engine No. 2 (S/N 4071853) Fourth Duty Cycle	Firing No. 1 Test C-028-88, 65 sec S/T		Firing No. 2 Test C-028-89, 35 sec S/T		Firing No. 3 Test C-028-90, 200 sec S/T		Firing No. 4 Test C-028-91, 20 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.48	0	14.46	0	14.43	0	14.44	0
Environmental Pressure, PSIA	.1160	0	.1110	0	.1210	0	.1060	0
Thrust, lbs	(69.4)		(68.9)		(68.1)		(68.0)	
Chamber Pressure, PSIA	100.18	100.73	99.51	100.36	98.33	98.21	98.24	98.08
Mixture Ratio, O/F	1.190	1.200	1.190	1.200	1.160	1.150	1.140	1.140
Specific Impulse, sec.	(262.4)		(261.2)		(261.9)		(262.6)	
Characteristic Velocity (C*), ft/sec.	4840	4849	4822	4828	4836	4832	4852	4849
Thrust Coefficient (Cf)	(1.75)		(1.75)		(1.75)		(1.75)	
Oxidizer Flowrate, lbs/sec.	.1437	.1448	.1434	.1447	.1395	.1391	.1381	.1377
Fuel Flowrate, lbs/sec.	.1208	.1205	.1204	.1208	.1205	.1206	.1208	.1207
Oxidizer Density, lb/ft^3	85.81	89.85	85.16	89.85	85.54	89.85	85.56	89.85
Fuel Density, lb/ft^3	53.10	54.66	52.75	54.66	52.65	54.66	52.84	54.66
Oxidizer Tank Pressure, PSIA	241.48		242.56		242.23		242.24	
Oxidizer Inlet Pressure, PSIA	197.48	195.00	197.56	195.00	200.63	195.00	200.64	195.00
Fuel Tank Pressure, PSIA	220.78		220.66		221.43		222.24	
Fuel Inlet Pressure, PSIA	197.58	195.00	196.96	195.00	198.63	195.00	198.64	195.00
Oxidizer Orifice Diameter, in.	.07840		.07840		.07840		.07840	
Fuel Orifice Diameter, in.	.08240		.08240		.08240		.08240	
Chamber Throat Diameter, in.	.7110		.7110		.7110		.7110	

Qual. Engine No. 2 (S/N 4071853)
Fourth Duty Cycle

PARAMETER	Firing No. 1 Test C-028-88, 65 sec S/T SITE	Firing No. 1 STANDARD	Firing No. 2 Test C-028-89, 35 sec S/T SITE	Firing No. 2 STANDARD	Firing No. 3 Test C-028-90, 200 sec S/T SITE	Firing No. 3 STANDARD	Firing No. 4 Test C-028-91, 20 sec S/T SITE	Firing No. 4 STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	85.0		89.0		87.0		86.0	
Environmental Temperature, °F	85.0		86.6		76.0		74.6	
Oxidizer Inlet Temperature, °F	115.6	70	117.1	70	121.8	70	107.7	70
Fuel Inlet Temperature, °F	116.0	70	123.9	70	123.9	70	119.0	70
Oxidizer Flowmeter Temperature, °F	119.5	70	127.1	70	122.7	70	122.5	70
Fuel Flowmeter Temperature, °F	117.7	70	128.2	70	128.2	70	125.4	70
Engine Temperature	150^{+} °F		150^{+} °F		150^{+} °F		150^{+} °F	
Oxidizer Valve Voltage, Volts	26.2		26.5		26.6		26.5	
Oxidizer Valve Current, Amperes	.55		.56		.58		.55	
Fuel Valve Voltage, Volts	26.0		25.5		26.2		26.5	
Fuel Valve Current, Amperes	.60		.59		.60		.57	

Note: Calculated data shown in parentheses.

Qual. Engine No. 3 (S/N 4069234) Off Design Testing	Firing No. 1 Test C-028-61, 4 sec S/T		Firing No. 2 Test C-028-68, 4 sec S/T		Firing No. 3 Test C-028-70, 4 sec S/T		Firing No. 4 Test C-028-55, 4 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.23	0	14.50	0	14.53	0	14.37	0
Environmental Pressure, PSIA	.0950	0	.1030	0	.1010	0	.0970	0
Thrust, lbs	63.2	68.4	63.6	64.8	87.6	69.4	63.4	69.0
Chamber Pressure, PSIA	87.98	93.08	94.68	94.14	127.48	99.31	87.62	93.24
Mixture Ratio, O/F	1.120	1.110	1.080	1.060	1.100	1.060	1.100	1.060
Specific Impulse, sec.	252.3	258.0	232.8	238.0	256.3	258.0	273.4	277.0
Characteristic Velocity (C*), ft/sec.	4489	4484	4429	4411	4767	4712	4829	4779
Thrust Coefficient (Cf)	1.809	1.852	1.692	1.735	1.731	1.759	1.822	1.864
Oxidizer Flowrate, lbs/sec.	.1322	.1397	.1417	.1405	.1792	.1384	.1215	.1283
Fuel Flowrate, lbs/sec.	.1183	.1254	.1315	.1321	.1626	.1308	.1104	.1209
Oxidizer Density, lb/ft^3	92.76	89.85	93.68	89.85	93.65	89.85	89.77	89.85
Fuel Density, lb/ft^3	56.23	54.66	57.09	54.66	56.80	54.66	54.58	54.66
Oxidizer Tank Pressure, PSIA	219.13		240.83		352.53		214.37	
Oxidizer Inlet Pressure, PSIA	175.93	195.00	192.53	195.00	281.03	195.00	179.37	195.00
Fuel Tank Pressure, PSIA	222.73		246.53		359.53		210.87	
Fuel Inlet Pressure, PSIA	176.43	195.00	191.13	195.00	270.53	195.00	172.87	195.00
Oxidizer Orifice Diameter, in.	.08490		.08490		.08490		.08490	
Fuel Orifice Diameter, in.	.07825		.07825		.07825		.07825	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 3 (S/N 4069234)
Off Design Testing

PARAMETER	Firing No. 1 Test C-028-61, 4 sec S/T SITE	STANDARD	Firing No. 2 Test C-028-68, 4 sec S/T SITE	STANDARD	Firing No. 3 Test C-028-70, 4 sec S/T SITE	STANDARD	Firing No. 4 Test C-028-55, 4 sec S/T SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	79.0		75.0		75.0		82.0	
Environmental Temperature, °F	54.8		68.2		70.3		84.3	
Oxidizer Inlet Temperature, °F	38.9	70.0	19.8	70.0	18.9	70.0	73	70.0
Fuel Inlet Temperature, °F	37.9	70.0	6.1	70.0	14.9	70.0	79.1	70.0
Oxidizer Flowmeter Temperature, °F	27.6	70.0	14.1	70.0	15.4	70.0	73.6	70.0
Fuel Flowmeter Temperature, °F	26.7	70.0	1.1	70.0	4.3	70.0	78.9	70.0
Engine Temperature	Amb.		Amb.		Amb.		Amb.	
Oxidizer Valve Voltage, Volts	26.5		26.5		26.6		26.4	
Oxidizer Valve Current, Amperes	.64		.67		.67		.61	
Fuel Valve Voltage, Volts	26.3		26.2		26.25		26.2	
Fuel Valve Current, Amperes	.68		.75		.745		.67	

Qual. Engine No. 3 (S/N 4069234) Off Design Testing	Firing No. 5 Test C-028-64, 4 sec S/T		Firing No. 6 Test C-028-54, 4 sec S/T		Firing No. 7 Test C-028-47, 4 sec S/T		Firing No. 8 Test C-028-46, 4 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.47	0	14.37	0	14.43	0	14.43	0
Environmental Pressure, PSIA	.1220	0	.1160	0	.0980	0	.1060	0
Thrust, lbs	69.5	71.6	92.0	74.1	64.6	72.2	68.8	70.2
Chamber Pressure, PSIA	102.42	102.60	128.07	101.23	91.23	100.01	97.88	97.88
Mixture Ratio, O/F	1.220	1.220	1.150	1.140	1.280	1.190	1.170	1.070
Specific Impulse, sec.	263.0	270.0	280.1	285.0	270.9	273.0	277.5	277.0
Characteristic Velocity (C*), ft/sec.	4952	4950	4982	4965	4889	4825	5046	4934
Thrust Coefficient (Cf)	1.709	1.757	1.809	1.845	1.783	1.819	1.770	1.807
Oxidizer Flowrate, lbs/sec.	.1454	.1456	.1757	.1387	.1337	.1440	.1338	.1312
Fuel Flowrate, lbs/sec.	.1189	.1191	.1528	.1218	.1048	.1207	.1141	.1221
Oxidizer Density, lb/ft^3	91.19	89.85	89.77	89.85	88.05	89.85	86.18	89.85
Fuel Density, lb/ft^3	55.14	54.66	54.58	54.66	52.39	54.66	52.85	54.66
Oxidizer Tank Pressure, PSIA	243.97		352.87		218.43		250.43	
Oxidizer Inlet Pressure, PSIA	193.47	195.00	279.37	195.00	174.93	195.00	203.93	195.00
Fuel Tank Pressure, PSIA	244.27		349.37		200.43		226.93	
Fuel Inlet Pressure, PSIA	193.77	195.00	276.37	195.00	165.43	195.00	185.93	195.00
Oxidizer Orifice Diameter, in.	.08490		.08490		.08490		.08490	
Fuel Orifice Diameter, in.	.07825		.07825		.07825		.07825	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 3 (S/N 4069234) Off Design Testing	Firing No. 5 Test C-028-64, 4 sec S/T		Firing No. 6 Test C-028-54, 4 sec S/T		Firing No. 7 Test C-028-47, 4 sec S/T		Firing No. 8 Test C-028-46, 4 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	71.5		82.0		82.0		84.0	
Environmental Temperature, °F	67.0		84.5		82.0		85.0	
Oxidizer Inlet Temperature, °F	58.6	70	71.9	70	94.5	70	116.8	70
Fuel Inlet Temperature, °F	56.8	70	80.2	70	121.3	70	119.8	70
Oxidizer Flowmeter Temperature, °F	56.6	70	73.6	70	-	70	-	70
Fuel Flowmeter Temperature, °F	60.0	70	78.9	70	129.8	70	131.0	70
Engine Temperature	-34 °F		Amb.		Amb.		Amb.	
Oxidizer Valve Voltage, Volts	26.4		26.4		26.0		26.1	
Oxidizer Valve Current, Amperes	.68		.60		.60		.60	
Fuel Valve Voltage, Volts	26.1		26.2		26.1		26.0	
Fuel Valve Current, Amperes	.735		.66		.65		.65	

Qual. Engine No. 3 (S/N 4069234) Off Design Testing	Firing No. 9 Test C-028-45, 4 sec S/T		Firing No. 10 Test C-028-66, 4 sec S/T		Firing No. 11 Test C-028-44, 4 sec S/T		Firing No. 12 Test C-028-48, 4 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.43	0	14.53	0	14.44	0	14.40	0
Environmental Pressure, PSIA	.1210	0	.1010	0	.1060	0	.1140	0
Thrust, lbs	89.5	74.2	67.7	67.9	69.0	72.0	71.8	73.6
Chamber Pressure, PSIA	126.68	102.75	103.73	101.72	98.59	100.72	101.82	101.82
Mixture Ratio, O/F	1.190	1.200	1.250	1.220	1.260	1.200	1.180	1.180
Specific Impulse, sec.	278.9	285.0	252.6	257.0	269.7	273.0	272.2	279.0
Characteristic Velocity (C*), ft/sec.	5045	5041	4947	4916	4926	4876	4933	4924
Thrust Coefficient (Cf)	1.779	1.818	1.644	1.680	1.763	1.801	1.776	1.820
Oxidizer Flowrate, lbs/sec.	.1745	.1419	.1489	.1451	.1425	.1439	.1430	.1430
Fuel Flowrate, lbs/sec.	.1464	.1186	.1191	.1193	.1133	.1199	.1208	.1211
Oxidizer Density, lb/ft^3	86.11	89.85	93.65	89.85	86.03	89.85	90.34	89.85
Fuel Density, lb/ft^3	52.74	54.66	57.01	54.66	52.55	54.66	54.69	54.66
Oxidizer Tank Pressure, PSIA	350.43		240.53		246.44		243.42	
Oxidizer Inlet Pressure, PSIA	273.93	195.00	197.53	195.00	195.44	195.00	194.92	195.00
Fuel Tank Pressure, PSIA	342.43		244.33		226.44		240.42	
Fuel Inlet Pressure, PSIA	272.93	195.00	193.53	195.00	186.44	195.00	194.92	195.00
Oxidizer Orifice Diameter, in.	.08490		.08490		.08490		.08490	
Fuel Orifice Diameter, in.	.07825		.07825		.07825		.07825	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 3 (S/N 4069234) Off Design Testing	Firing No. 9 Test C-028-45, 4 sec S/T		Firing No. 10 Test C-028-66, 4 sec S/T		Firing No. 11 Test C-028-44, 4 sec S/T		Firing No. 12 Test C-028-48, 4 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490		4.490	
Chamber Throat Area, sq. in.	.3970		.3970		.3970		.3970	
Chamber Exit Area, sq. in.	15.834		15.834		15.834		15.834	
Local Ambient Temperature, °F	84.0		75.0		84.0		75.0	
Environmental Temperature, °F	93.2		68.8		103.2		93.2	
Oxidizer Inlet Temperature, °F	118.0	70	18.5	70	118.5	70	70.0	70
Fuel Inlet Temperature, °F	122.0	70	9.9	70	124.5	70	71.9	70
Oxidizer Flowmeter Temperature, °F	-	70	14.7	70	-	70	66.8	70
Fuel Flowmeter Temperature, °F	133.8	70	3.7	70	139.0	70	76.4	70
Engine Temperature	Amb.		-22 °F		154 °F		150 °F	
Oxidizer Valve Voltage, Volts	26.3		26.5		26.2		-	
Oxidizer Valve Current, Amperes	.60		.665		.55		.53	
Fuel Valve Voltage, Volts	26.0		26.2		26.0		25.8	
Fuel Valve Current, Amperes	.64		.75		.60		.59	

Qual. Engine No. 3 (S/N 4069234) Off Design Testing	Firing No. 13 Test C-028-50, 4 sec S/T		Firing No. 14 Test C-028-52, 4 sec S/T		Hot Fire Burst Pressure Test Test C-028-71, 4 sec S/T			
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.40	0	14.38	0	14.54	0		
Environmental Pressure, PSIA	.1160	0	.1050	0	.1460	0		
Thrust, lbs	79.2	71.4	70.2	71.2	114.7	76.0		
Chamber Pressure, PSIA	111.45	98.15	97.49	96.84	158.14	102.79		
Mixture Ratio, O/F	1.930	1.230	.723	1.040	1.180	1.160		
Specific Impulse, sec.	272.5	268.0	247.2	281.0	279.3	284.0		
Characteristic Velocity (C*), ft/sec.	4901	4714	4387	4880	4922	4902		
Thrust Coefficient (Cf)	1.790	1.832	1.814	1.853	1.827	1.863		
Oxidizer Flowrate, lbs/sec.	.1913	.1466	.1192	.1293	.2224	.1440		
Fuel Flowrate, lbs/sec.	.0993	.1194	.1648	.1241	.1882	.1239		
Oxidizer Density, lb/ft^3	90.31	89.85	90.31	89.85	90.45	89.85		
Fuel Density, lb/ft^3	54.64	54.66	54.63	54.66	54.99	54.66		
Oxidizer Tank Pressure, PSIA	363.40		214.39		403.54			
Oxidizer Inlet Pressure, PSIA	276.40	195.00	180.89	195.00	377.04	195.00		
Fuel Tank Pressure, PSIA	208.90		354.39		399.54			
Fuel Inlet Pressure, PSIA	178.90	195.00	271.39	195.00	370.54	195.00		
Oxidizer Orifice Diameter, in.	.08490		.08490		.08490			
Fuel Orifice Diameter, in.	.07825		.07825		.07825			
Chamber Throat Diameter, in.	.7111		.7111		.7111			

Qual. Engine No. 3 (S/N 4069234)
Off Design Testing

PARAMETER	Firing No. 13 Test C-028-50, 4 sec S/T		Firing No. 14 Test C-028-52, 4 sec S/T		Hot Fire Burst Pressure Test Test C-028-71, 4 sec S/T			
	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.490		4.490		4.490			
Chamber Throat Area, sq. in.	.3970		.3970		.3970			
Chamber Exit Area, sq. in.	15.834		15.834		15.834			
Local Ambient Temperature, °F	80.0		83.5		75.0			
Environmental Temperature, °F	84.3		84.0		72.5			
Oxidizer Inlet Temperature, °F	69.8	70	71.9	70	64.8	70		
Fuel Inlet Temperature, °F	76.6	70	79.2	70	67.5	70		
Oxidizer Flowmeter Temperature, °F	67.0	70	67.0	70	64.2	70		
Fuel Flowmeter Temperature, °F	76.9	70	77.6	70	65.6	70		
Engine Temperature	Amb.		Amb.		Amb.			
Oxidizer Valve Voltage, Volts	-		26.4					
Oxidizer Valve Current, Amperes	.59		.61					
Fuel Valve Voltage, Volts	25.8		26.2					
Fuel Valve Current, Amperes	.65		.66					

Qual. Engine No. 4 (S/N 4071863) First Duty Cycle	Firing No. 1 Test C-028-102, 15 sec S/T		Firing No. 2 Test C-028-103, 15 sec S/T		Firing No. 3 Test C-028-104, 15 sec S/T		Firing No. 4 Test C-028-105, 15 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.45	0	14.45	0	14.45	0	14.43	0
Environmental Pressure, PSIA	.1260	0	.1240	0	.1330	0	.1320	0
Thrust, lbs	73.4	74.2	73.1	73.7	72.5	73.5	73.1	73.9
Chamber Pressure, PSIA	106.30	104.78	106.30	104.76	105.69	104.19	105.98	104.20
Mixture Ratio, O/F	1.240	1.200	1.250	1.170	1.190	1.190	1.175	1.200
Specific Impulse, sec.	274.9	280.0	272.3	275.0	270.0	278.0	270.2	279.0
Characteristic Velocity (C*), ft/sec.	5088	5055	5060	4996	5031	5032	5007	5025
Thrust Coefficient (Cf)	1.74	1.78	1.73	1.77	1.73	1.78	1.74	1.79
Oxidizer Flowrate, lbs/sec.	.1476	.1443	.1491	.1446	.1459	.1438	.1461	.1443
Fuel Flowrate, lbs/sec.	.1194	.1205	.1194	.1234	.1226	.1207	.1244	.1206
Oxidizer Density, lb/ft^3	89.55	89.85	89.25	89.85	88.95	89.85	88.95	89.85
Fuel Density, lb/ft^3	54.59	54.66	54.27	54.66	54.55	54.66	54.51	54.66
Oxidizer Tank Pressure, PSIA	268.95		270.45		264.44		264.23	
Oxidizer Inlet Pressure, PSIA	200.95	195.00	202.95	195.00	199.94	195.00	199.93	195.00
Fuel Tank Pressure, PSIA	233.65		237.25		240.64		245.93	
Fuel Inlet Pressure, PSIA	194.95	195.00	190.95	195.00	199.64	195.00	202.93	195.00
Oxidizer Orifice Diameter, in.	.07905		.07905		.07905		.07905	
Fuel Orifice Diameter, in.	.08520		.08520		.08520		.08520	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 4 (S/N 4071863) First Duty Cycle	Firing No. 1 Test C-028-102, 15 sec S/T		Firing No. 2 Test C-028-103, 15 sec S/T		Firing No. 3 Test C-028-104, 15 sec S/T		Firing No. 4 Test C-028-105, 15 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.442		4.442		4.442		4.442	
Chamber Throat Area, sq. in.	.3971		.3971		.3971		.3971	
Chamber Exit Area, sq. in.	15.497		15.497		15.497		15.497	
Local Ambient Temperature, °F	90		90		92		92	
Environmental Temperature, °F	72.4		91.8		92.6		97.0	
Oxidizer Inlet Temperature, °F	80.0	70	92.6	70	89.8	70	88.8	70
Fuel Inlet Temperature, °F	80.8	70	85.0	70	85.1	70	85.1	70
Oxidizer Flowmeter Temperature, °F	76.9	70	81.2	70	84.0	70	84.2	70
Fuel Flowmeter Temperature, °F	79.8	70	80.4	70	81.0	70	82.2	70
Engine Temperature	Amb.		Amb.		Amb.		Amb.	
Oxidizer Valve Voltage, Volts	26.2		26.0		26.6		26.6	
Oxidizer Valve Current, Amperes	.59		.56		.57		.56	
Fuel Valve Voltage, Volts	25.8		25.7		26.3		26.1	
Fuel Valve Current, Amperes	.62		.57		.57		.57	

Qual. Engine No. 4 (S/N 4071863) Second Duty Cycle	Firing No. 1 Test C-028-107, 10 sec S/T		Firing No. 2 Test C-028-108, 10 sec S/T		Firing No. 3 Test C-028-109, 10 sec S/T		Firing No. 4 Test C-028-110, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.43	0	14.41	0	14.39	0	14.40	0
Environmental Pressure, PSIA	.1240	0	.1260	0	.1260	0	.1320	0
Thrust, lbs	72.7	72.7	72.9	72.8	73.0	72.9	72.5	72.4
Chamber Pressure, PSIA	105.53	102.96	105.06	102.14	105.14	102.27	104.75	101.83
Mixture Ratio, O/F	1.188	1.170	1.174	1.170	1.199	1.180	1.188	1.170
Specific Impulse, sec.	270.6	277.0	270.9	278.0	271.0	277.0	270.0	276.0
Characteristic Velocity (C*), ft/sec.	5019	5012	4986	4983	4988	4971	4986	4967
Thrust Coefficient (Cf)	1.73	1.78	1.75	1.79	1.75	1.79	1.74	1.79
Oxidizer Flowrate, lbs/sec.	.1459	.1418	.1454	.1413	.1469	.1424	.1458	.1411
Fuel Flowrate, lbs/sec.	.1228	.1208	.1239	.1206	.1225	.1204	.1227	.1208
Oxidizer Density, lb/ft^3	88.93	89.85	88.63	89.85	88.54	89.85	88.56	89.85
Fuel Density, lb/ft^3	54.39	54.66	54.31	54.66	54.31	54.66	54.28	54.66
Oxidizer Tank Pressure, PSIA	262.13		262.41		264.89		263.40	
Oxidizer Inlet Pressure, PSIA	203.83	195.00	204.61	195.00	205.19	195.00	205.60	195.00
Fuel Tank Pressure, PSIA	242.63		246.41		243.89		243.40	
Fuel Inlet Pressure, PSIA	201.23	195.00	203.71	195.00	201.79	195.00	201.40	195.00
Oxidizer Orifice Diameter, in.	.07905		.07905		.07905		.07905	
Fuel Orifice Diameter, in.	.08520		.08520		.08520		.08520	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 4 (S/N 4071863) Second Duty Cycle	Firing No. 1 Test C-028-107, 10 sec S/T		Firing No. 2 Test C-028-108, 10 sec S/T		Firing No. 3 Test C-028-109, 10 sec S/T		Firing No. 4 Test C-028-110, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.442		4.442		4.442		4.442	
Chamber Throat Area, sq. in.	.3971		.3971		.3971		.3971	
Chamber Exit Area, sq. in.	15.497		15.497		15.497		15.497	
Local Ambient Temperature, °F	100		97		97		92	
Environmental Temperature, °F	96.8		99.6		96.8		101.8	
Oxidizer Inlet Temperature, °F	85.0	70	92.0	70	92.0	70	92.0	70
Fuel Inlet Temperature, °F	85.2	70	91.8	70	92.0	70	91.8	70
Oxidizer Flowmeter Temperature, °F	83.2	70	87.2	70	88.5	70	88.2	70
Fuel Flowmeter Temperature, °F	84.6	70	87.6	70	87.4	70	88.4	70
Engine Temperature	Amb.		Amb.		Amb.		Amb.	
Oxidizer Valve Voltage, Volts	27.0		26.9		26.8		26.6	
Oxidizer Valve Current, Amperes	.62		.58		.57		.57	
Fuel Valve Voltage, Volts	26.5		26.5		26.5		26.3	
Fuel Valve Current, Amperes	.63		.58		.57		.57	

Qual. Engine No. 4 (S/N 4071863) Third Duty Cycle	Firing No. 1 Test C-028-112, 10 sec S/T		Firing No. 2 Test C-028-113, 10 sec S/T		Firing No. 3 Test C-028-114, 10 sec S/T		Firing No. 4 Test C-028-115, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.42	0	14.42	0	14.40	0	14.38	0
Environmental Pressure, PSIA	.1140	0	.1090	0	.1080	0	.1050	0
Thrust, lbs	72.0	72.9	70.9	71.7	71.5	71.8	71.7	72.8
Chamber Pressure, PSIA	105.57	104.32	104.97	103.68	104.95	103.02	104.78	104.10
Mixture Ratio, O/F	1.173	1.190	1.200	1.190	1.180	1.180	1.179	1.150
Specific Impulse, sec.	267.5	275.0	266.3	272.0	268.0	274.0	269.4	274.0
Characteristic Velocity (C*), ft/sec.	5012	5024	5040	5032	5027	5022	5032	5001
Thrust Coefficient (Cf)	1.72	1.76	1.70	1.74	1.72	1.76	1.72	1.76
Oxidizer Flowrate, lbs/sec.	.1453	.1441	.1452	.1432	.1444	.1416	.1440	.1421
Fuel Flowrate, lbs/sec.	.1239	.1213	.1210	.1201	.1224	.1205	.1221	.1240
Oxidizer Density, lb/ft^3	89.18	89.85	88.95	89.85	88.69	89.85	88.56	89.85
Fuel Density, lb/ft^3	54.48	54.66	54.42	54.66	54.37	54.66	54.33	54.66
Oxidizer Tank Pressure, PSIA	260.32		260.32		260.30		259.58	
Oxidizer Inlet Pressure, PSIA	198.32	195.00	199.62	195.00	201.70	195.00	199.38	195.00
Fuel Tank Pressure, PSIA	241.42		237.32		241.40		239.88	
Fuel Inlet Pressure, PSIA	200.52	195.00	198.12	195.00	200.30	195.00	193.48	195.00
Oxidizer Orifice Diameter, in.	.07905		.07905		.07905		.07905	
Fuel Orifice Diameter, in.	.08520		.08520		.08520		.08520	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 4 (S/N 4071863)
Third Duty Cycle

PARAMETER	Firing No. 1 Test C-028-112, 10 sec S/T		Firing No. 2 Test C-028-113, 10 sec S/T		Firing No. 3 Test C-028-114, 10 sec S/T		Firing No. 4 Test C-028-115, 10 sec S/T	
	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.442		4.442		4.442		4.442	
Chamber Throat Area, sq. in.	.3971		.3971		.3971		.3971	
Chamber Exit Area, sq. in.	15.497		15.497		15.497		15.497	
Local Ambient Temperature, °F	94		102		102		102	
Environmental Temperature, °F	92.4		97.8		99.2		102	
Oxidizer Inlet Temperature, °F	84.0	70	89.0	70	92.0	70	106	
Fuel Inlet Temperature, °F	84.4	70	89.8	70	92.0	70	91.0	70
Oxidizer Flowmeter Temperature, °F	79.9	70	83.0	70	86.6	70	90.8	70
Fuel Flowmeter Temperature, °F	82.0	70	83.6	70	85.4	70	88.2	70
Engine Temperature	Amb.		Amb.		Amb.		87.0	70
Oxidizer Valve Voltage, Volts	26.6		26.6		26.5		Amb.	
Oxidizer Valve Current, Amperes	.62		.57		.56		26.5	
Fuel Valve Voltage, Volts	26.4		26.5		26.2		.56	
Fuel Valve Current, Amperes	.63		.58		.57		26.2	
							.57	

Qual. Engine No. 4 (S/N 4071863) Fourth Duty Cycle	Firing No. 1 Test C-028-116, 10 sec S/T		Firing No. 2 Test C-028-117, 10 sec S/T		Firing No. 3 Test C-028-118, 10 sec S/T		Firing No. 4 Test C-028-119, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Atmospheric Pressure, PSIA	14.38	0	14.38	0	14.38	0	14.38	0
Environmental Pressure, PSIA	.1070	0	.1110	0	.1130	0	.1160	0
Thrust, lbs	71.4	72.0	72.2	72.8	72.0	73.0	72.7	74.0
Chamber Pressure, PSIA	105.08	103.61	104.98	103.32	104.78	103.70	104.78	104.09
Mixture Ratio, O/F	1.197	1.190	1.203	1.210	1.218	1.210	1.200	1.200
Specific Impulse, sec.	268.1	274.0	268.4	275.0	271.2	278.0	271.8	280.0
Characteristic Velocity (C*), ft/sec.	5043	5031	4988	4996	5044	5040	5006	5027
Thrust Coefficient (Cf)	1.71	1.75	1.73	1.77	1.73	1.77	1.75	1.79
Oxidizer Flowrate, lbs/sec.	.1451	.1428	.1469	.1449	.1458	.1442	.1459	.1444
Fuel Flowrate, lbs/sec.	.1212	.1204	.1221	.1193	.1197	.1188	.1216	.1202
Oxidizer Density, lb/ft^3	88.41	89.85	88.46	89.85	88.55	89.85	88.58	89.85
Fuel Density, lb/ft^3	54.31	54.66	54.26	54.66	54.25	54.66	54.34	54.66
Oxidizer Tank Pressure, PSIA	259.58		263.18		262.58		263.28	
Oxidizer Inlet Pressure, PSIA	200.88	195.00	200.48	195.00	199.38	195.00	199.58	195.00
Fuel Tank Pressure, PSIA	238.58		242.88		237.88		237.58	
Fuel Inlet Pressure, PSIA	198.38	195.00	201.68	195.00	198.08	195.00	196.38	195.00
Oxidizer Orifice Diameter, in.	.07905		.07905		.07905		.07905	
Fuel Orifice Diameter, in.	.08520		.08520		.08520		.08520	
Chamber Throat Diameter, in.	.7111		.7111		.7111		.7111	

Qual. Engine No. 4 (S/N 4071863) Fourth Duty Cycle	Firing No. 1 Test C-028-116, 10 sec S/T		Firing No. 2 Test C-028-117, 10 sec S/T		Firing No. 3 Test C-028-118, 10 sec S/T		Firing No. 4 Test C-028-119, 10 sec S/T	
PARAMETER	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD	SITE	STANDARD
Chamber Exit Diameter, in.	4.442		4.442		4.442		4.442	
Chamber Throat Area, sq. in.	.3971		.3971		.3971		.3971	
Chamber Exit Area, sq. in.	15.497		15.497		15.497		15.497	
Local Ambient Temperature, °F	100		96		85		85	
Environmental Temperature, °F	104.8		101.8		93.2		97.0	
Oxidizer Inlet Temperature, °F	91.0	70	89.0	70	93.0	70	91.0	70
Fuel Inlet Temperature, °F	90.8	70	89.2	70	92.6	70	91.0	70
Oxidizer Flowmeter Temperature, °F	90.2	70	89.4	70	88.4	70	88.0	70
Fuel Flowmeter Temperature, °F	87.4	70	94.8	70	86.6	70	86.4	70
Engine Temperature	Amb.		Amb.		Amb.		Amb.	
Oxidizer Valve Voltage, Volts	26.8		26.8		26.9		26.9	
Oxidizer Valve Current, Amperes	.53		.54		.57		.56	
Fuel Valve Voltage, Volts	26.5		26.6		26.6		26.6	
Fuel Valve Current, Amperes	.54		.54		.57		.57	

APPENDIX D

SELECTED VIBRATION QUALIFICATION DATA

The selected data contained in this appendix is considered to be representative of the vibration qualification results and illustrates some of the observations presented in the preceeding text.

As described, the vibration qualification consisted of a series of preliminary tests on previously hot-fired engines (Runs 1 - 26) followed by the official tests (Runs 27 - 32) on TCA 4. All sine sweep testing was conducted during odd numbered runs while even numbered runs comprise the random testing series. The data from the attempted qualification of the basic, unmodified engine (Runs 1 - 14) is found in Table V, associated FIG 27, and FIG 28 through 31. Phase relationships and amplification factors between various components of the engine and module for these tests are found in Tables VI and VII. This data was representative of that during the later pre-qualification and official qualification testing. Table VIII and referenced FIG 32 present data from the preliminary qualification of the nozzle flange and trunnion mount reinforcement fixtures incorporated in the basic engine. The official qualification of the O-ring nozzle support was conducted during Runs 21 - 26 and data is found in Table IX, FIG 33. Data for the official qualification of the nozzle flange reinforcement collar is reviewed in Table X, FIG 34 through 36. Tables XI through XIII present a comparison and correlation of all sine sweep test data for the entire program.

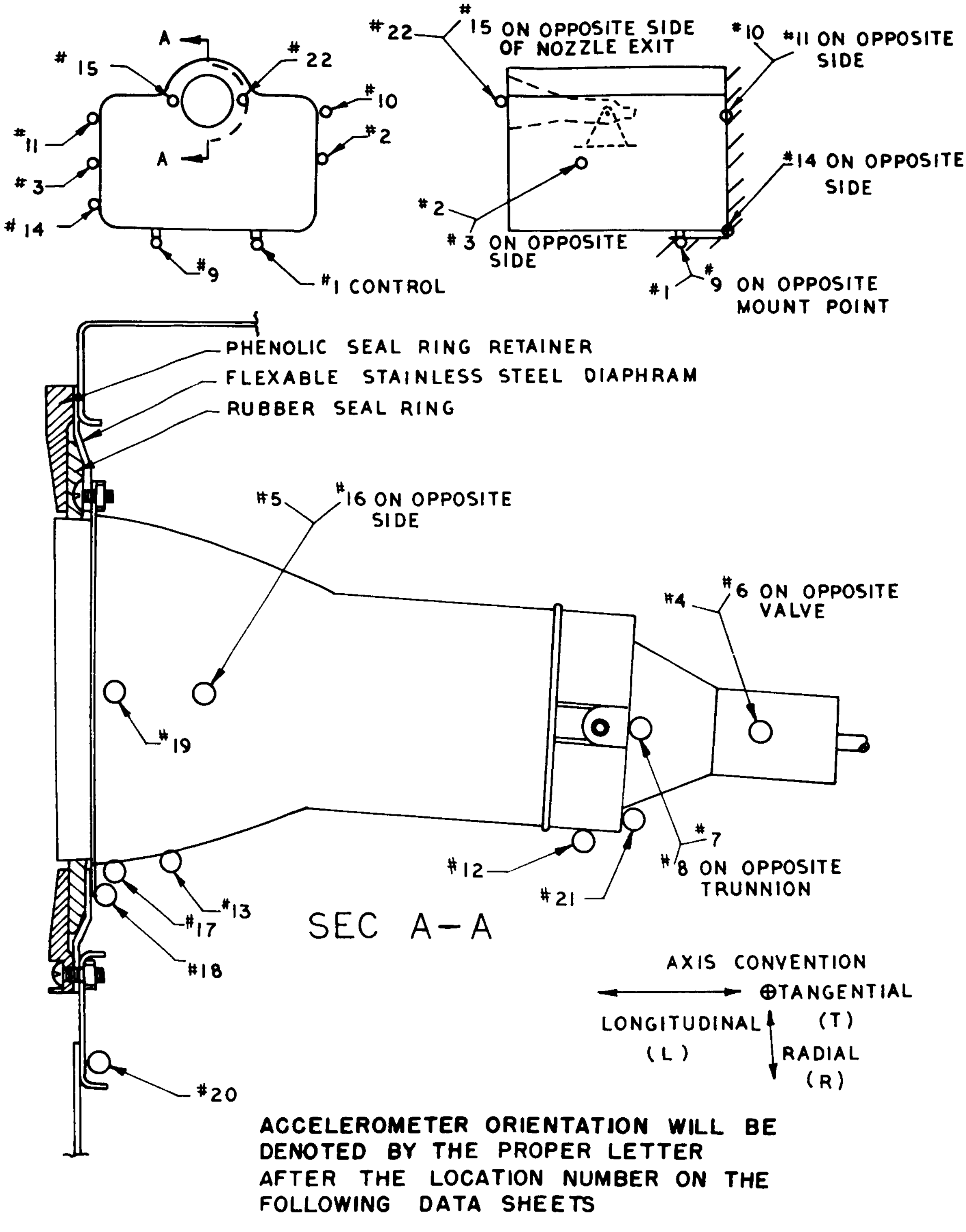


FIG 27 ACCELEROMETER LOCATIONS FOR VIBRATION TESTS 1 THROUGH 14

TABLE V

PRE-QUALIFICATION
SINUSOIDAL SWEEP RESONANT FREQUENCIES AND PEAK AMPLITUDES

Peak Amplitudes (G's) for Designated Accelerometers
(Refer to FIG 27 for Location and Orientation)

Test No. (Axis of Vibr.)	Resonant Freq.	1T	2T	3T	4R	5T	6T	7T	8T	9T	10T	
3 (Tangential)	80	6	40	42	10	50	10	32	35	11	7	TCA 3- Basic Unmodified SE-7 Engine
	170	8	33	18	12	28	9	20	20	10	12	
	290	7	12	11	29	18	6	22	23	8	17	
	345	9	11	12	16	22	5	21	24	12	18	
	750	9	16	20	22	70	9	12	12	12	9	
	975	10	17	65	14	100	11	45	60	35	28	
	1350	12	21	25	18	80	7	38	25	50	16	
	1500	9	18	11	28	60	5	40	50	17	9	
	1825	10	22	22	9	60	8	50	43	30	7	

Test No. (Axis of Vibr.)	Resonant Freq.	1R	2R	3R	4R	12R	6T	7R	8R	9T	11R	
5 (Radial)	140	6	15	19	25	26	23	21	20	4	8	TCA 3 - Same as above
	300	11	15	20	77	52	43	25	24	7	15	
	900	10	20	14	20	17	31	50	40	41	45	

Test No. (Axis of Vibr.)	Resonant Freq.	1L	2L	3L	4R	12L	6T	7L	8L	9L	10L	
7 (Longitudinal)	140	6	10	8	19	19	9	18	21	6	9	TCA 3 - Same as above
	170	5	8	6	30	30	6	19	22	5	5	
	270	7	20	24	55	37	23	18	20	9	8	
	570	10	30	40	13	17	50	20	19	9	13	
	760	11	16	21	14	29	18	30	19	20	19	
	1075	11	18	21	20	27	17	45	27	31	21	

Test No. (Axis of Vibr.)	Resonant Freq.	1L	13R	11L	4T	12L	6L	7L	8L	9L	10L	
9 (Longitudinal)	50	6	21	5	7	9	8	9	12	5	6	TCA 1 - Basic Unmodified SE-7 Engine
	140	6	18	7	16	18	14	16	20	6	8	
	185	7	50	10	30	23	20	16	20	8	9	
	275	10	40	10	62	23	30	26	35	12	13	
	525	10	32	13	13	18	18	23	30	12	9	
	780	9	60	17	29	15	17	17	15	22	25	
	1060	11	19	43	32	20	30	32	42	29	19	

Test No. (Axis of Vibr.)	Resonant Freq.	1R	13R	16T	4R	12R	6T	7R	8R	14R	15L	
11 (Radial)	135	9	21	30	22	20	15	23	25	8	39	TCA 1 with Gusset Reinforced Nozzle Flange after Failure of Previous Random Series
	275	6	7	13	43	27	11	14	18	6	43	
	320	10	25	32	85	55	28	30	40	17	70	
	535	←				Negligible				→	54	
	585	←				Negligible				→	80	
	640	9	25	20	10	6	17	11	10	16	109	
	890	10	70	57	53	29	55	60	50	60	85	
	970	11	145	50	31	5	56	37	25	45	75	

Test No. (Axis of Vibr.)	Resonant Freq.	1L	7L	8L	20L	12R	17R	18L	19T	4T	21L	
13A (Longitudinal)	160	5	19	28	45	17	17	20	10	6	17	TCA 3 with earlier weld failures repaired. This series was conducted to determine phase relationships of 20 and 18, 12 and 17, and 4 and 19.
	270	7	27	32	83	49	38	40	27	Neg.	52	
	525	12	26	45	82	12	40	52	44		10	
	770	9	15	34	58	12	49	48	26		5	
	1080	13	46	98	48	17	104	58	72		9	
	1850	12	88	132	90	24	116	104	278		14	

Test No. (Axis of Vibr.)	Resonant Freq.	1L	7L	8L	20R	12T	17R	22T	19T	
13B (Longitudinal)	150	9	27	32	5	34	3	6	6	Same as above for 12, 19 and 22, 17 and 20
	260	12	18	19	11	40	23	10	21	
	550	18	23	40	35	13	32	49	43	
	790	20	32	51	39	18	95	48	56	
	1070	28	32	40	22	8	67	60	68	
	1950	16	96	100	48	11	100	36	180	

TABLE VI

PHASE RELATIONSHIPS OF SELECTED ACCELEROMETER RESONANT FREQUENCIES DURING PRE-QUALIFICATION VIBRATION TEST 13
(Refer to FIG 27 for Location and Orientation)

Test No. (Axis of Vibr.)	Resonant Freq.	12 Leads 17	20 Leads 18	19 Leads 4	Remarks
13A (Longitudinal) ↓	270	0°	0°	60°	(1) Lots of data hash
	520	180°(1)	0°	180°	(2) Harmonic on 17R larger than fundamental
	1080	(2)	25°	(3)	(3) High amplitude harmonic on 19T
	1850	-	-	45°	
		19 Leads 22	20 Leads 17		
13B (Longitudinal) ↓	560	-	(4)		(4) High amplitude harmonic on 17R
	813	90°	10°		
	1070	0°	(1)		
	1945	70°	45°		

TABLE VII

AMPLIFICATION OF SINE SWEEP G-LEVELS FOR VARIOUS ENGINE/MODULE POSITIONS

Test No. (Axis of Vibr.)	Resonant Frequency	Ratio of Peak G Levels for Designated* Accelerometers											
		7/1	8/1	6/7	6/8	5/7	5/8	4/7	4/8	12/7	12/8	13/7	13/8
3	80	5.3	5.8	0.3	0.3	1.6	1.4	NM	NM	NM	NM	NM	NM
(Tangential)	170	2.5	2.5	0.5	0.5	1.4	1.4						
	290	3.1	3.3	0.3	0.3	0.8	0.8						
	345	2.3	2.7	0.2	0.2	1.0	0.9						
	750	1.3	1.3	0.8	0.8	5.8	5.8						
	975	4.5	6.0	0.2	0.2	2.2	1.7						
	1350	3.2	2.1	0.2	0.3	2.1	3.2						
	1500	4.4	5.6	0.1	0.1	1.5	1.2						
	1825	5.0	4.3	0.2	0.2	1.2	1.4						
5	140	3.5	3.3	NM	NM	NM	NM	1.2	1.3	1.2	1.3	NM	NM
(Radial)	300	2.3	2.2					3.1	3.2	1.0	1.0		
	900	5.0	4.0					0.4	0.5	0.6	0.8		
7	270	2.6	2.9	NM	NM	NM	NM	NM	NM	2.1	1.8	NM	NM
(Longitudinal)	575	2.0	1.9							0.9	0.9		
	1070	4.1	2.5							0.6	1.0		
9	50	1.5	2.0	0.9	0.7	NM	NM	NM	NM	1.0	0.8	NM	NM
(Longitudinal)	185	2.3	2.9	1.3	1.0					1.4	1.2		
	275	2.6	3.5	1.2	0.9					0.9	0.7		
	525	2.3	3.0	0.8	0.6					0.8	0.6		
	790	1.9	1.7	1.0	1.1					0.9	1.0		
	1060	2.9	3.8	0.9	0.7					0.6	0.5		
11	135	2.6	2.8	NM	NM	NM	NM	1.0	0.9	0.9	0.8	0.9	0.8
(Radial)	320	3.0	4.0					2.8	2.1	1.8	1.4	0.8	0.6
	640	1.2	1.1					0.9	1.0	0.5	0.6	2.3	2.5
	890	6.0	5.0					0.9	1.1	0.5	0.6	1.2	1.4

*See Fig. 27 for accelerometer notations
NM - Not monitored

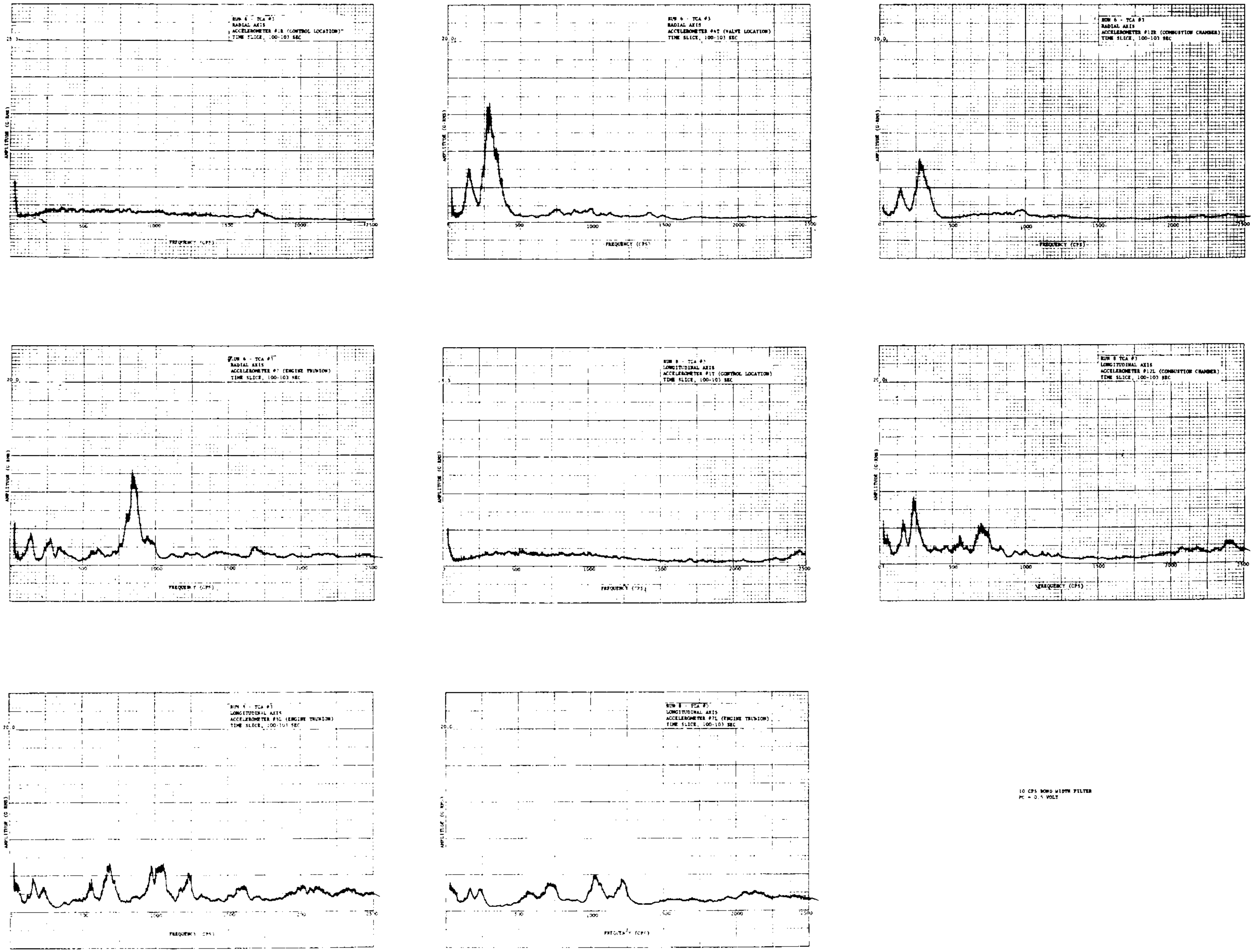


FIG 28 POWER SPECTRAL DENSITY (PSD) ANALYSIS OF RANDOM VIBRATION DATA; TESTS 6 AND 8

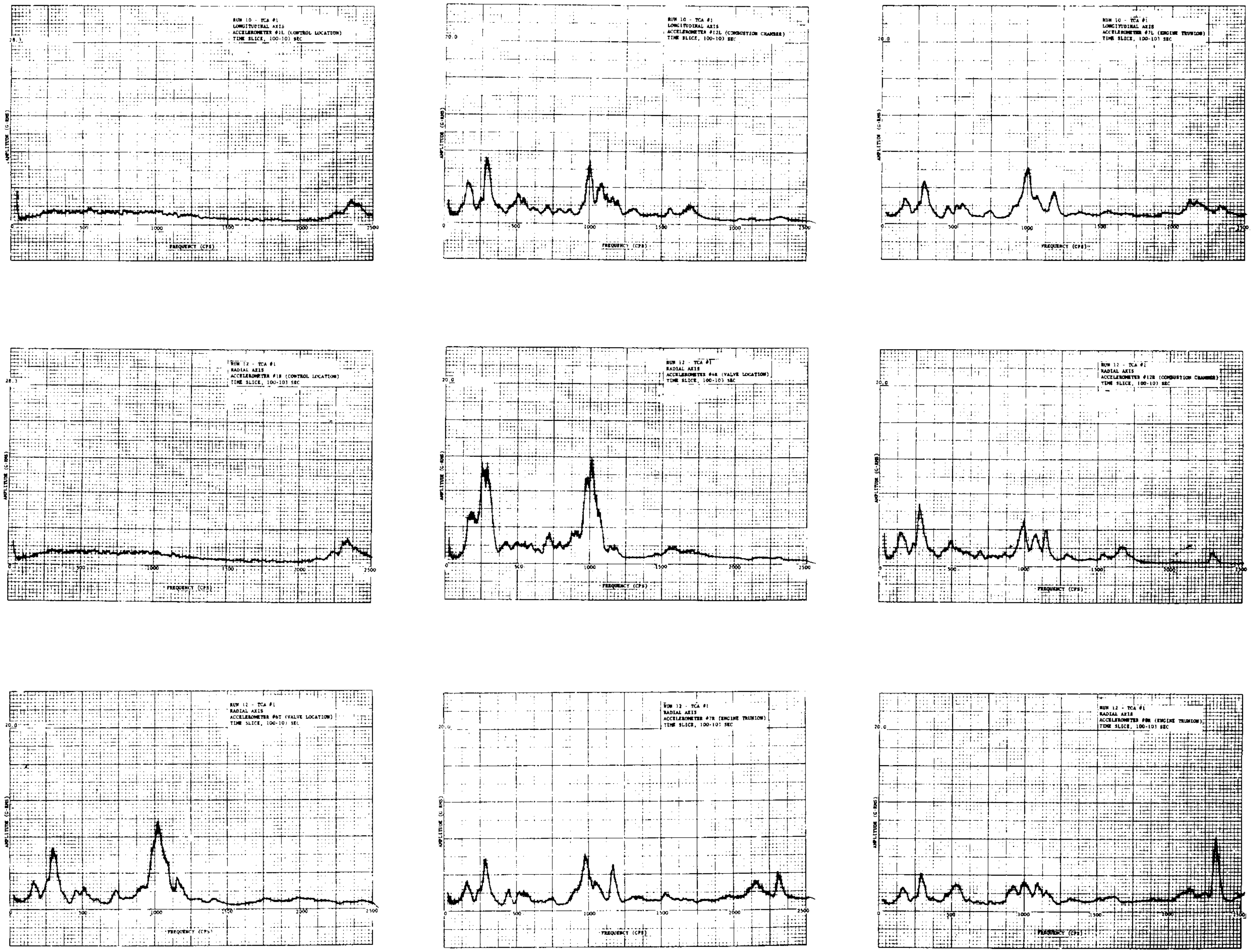


FIG 29 POWER SPECTRAL DENSITY (PSD) ANALYSIS OF RANDOM VIBRATION DATA; TESTS 10 AND 12

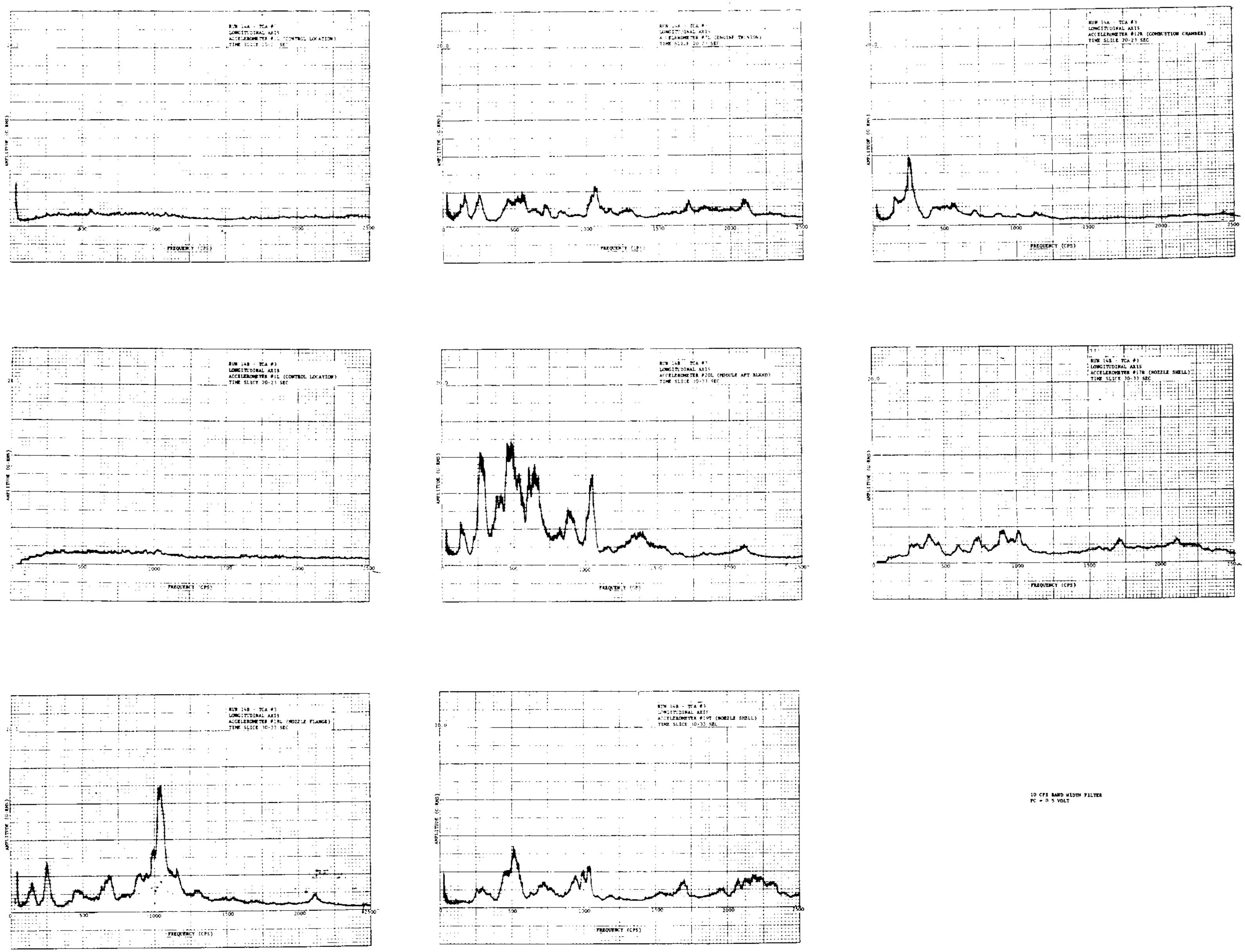


FIG 30 POWER SPECTRAL DENSITY (PSD) ANALYSIS OF RANDOM VIBRATION DATA; TESTS 14A AND 14B

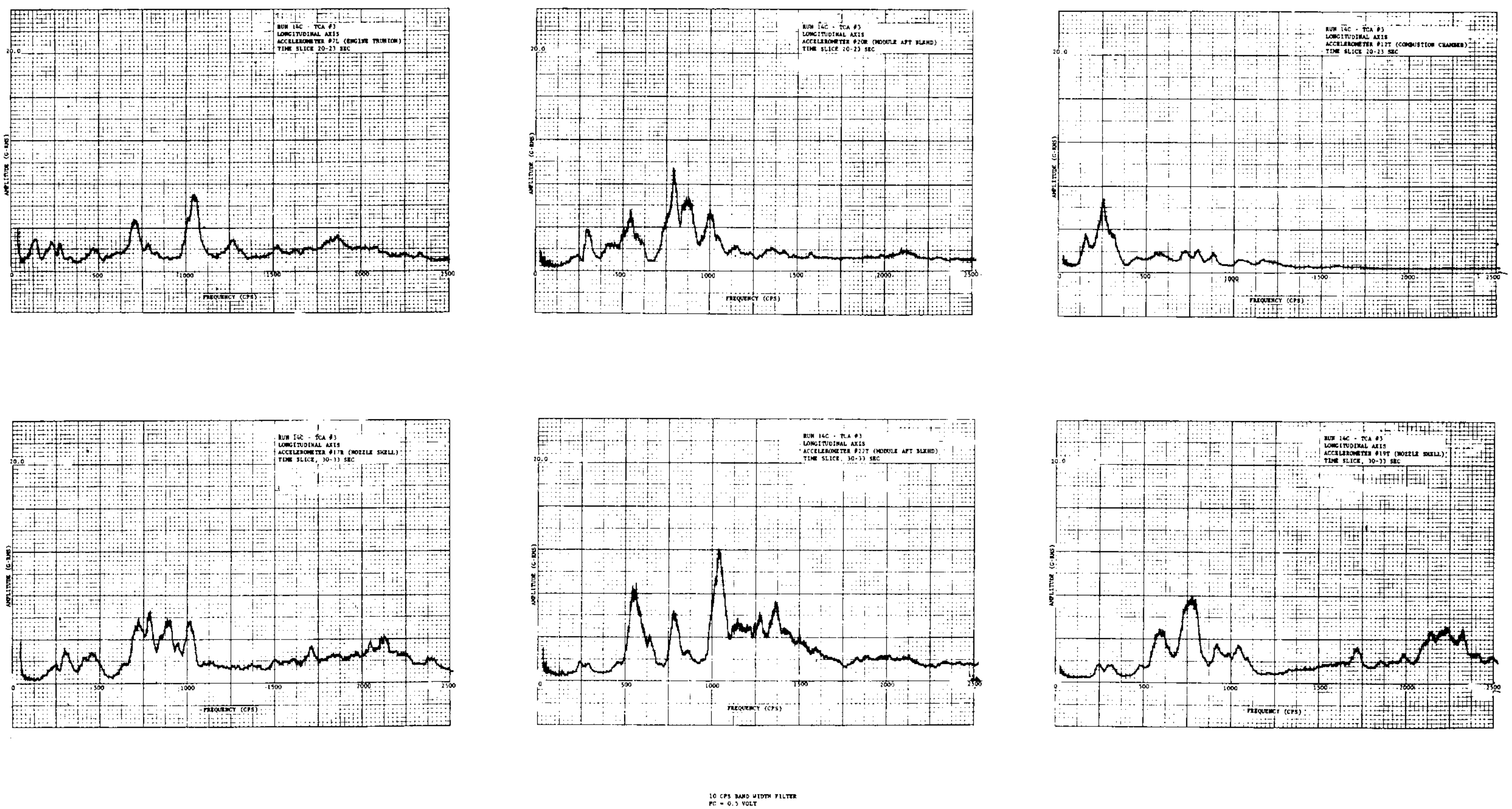


FIG 31 POWER SPECTRAL DENSITY (PSD) ANALYSIS OF RANDOM VIBRATION DATA; TEST 14C

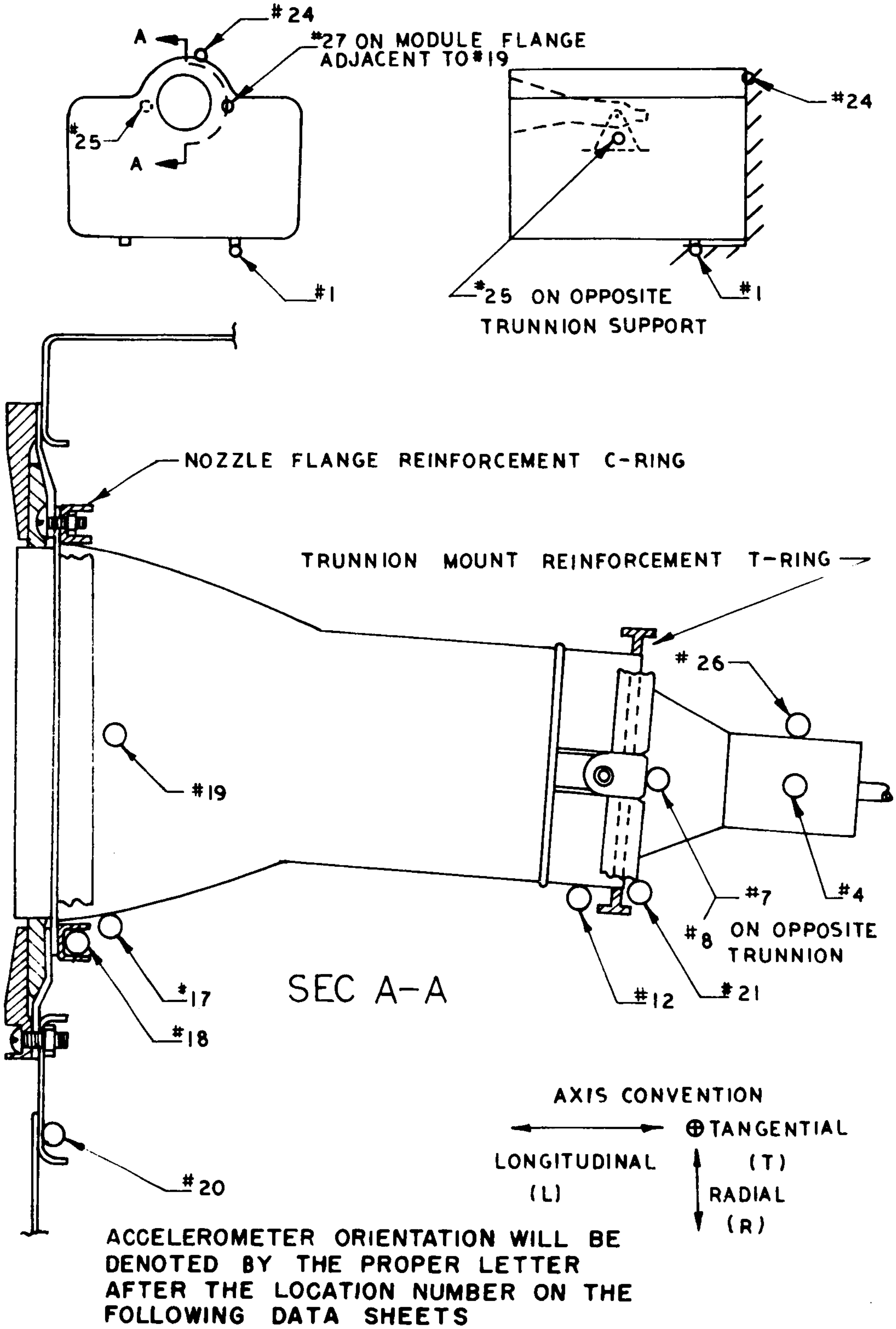
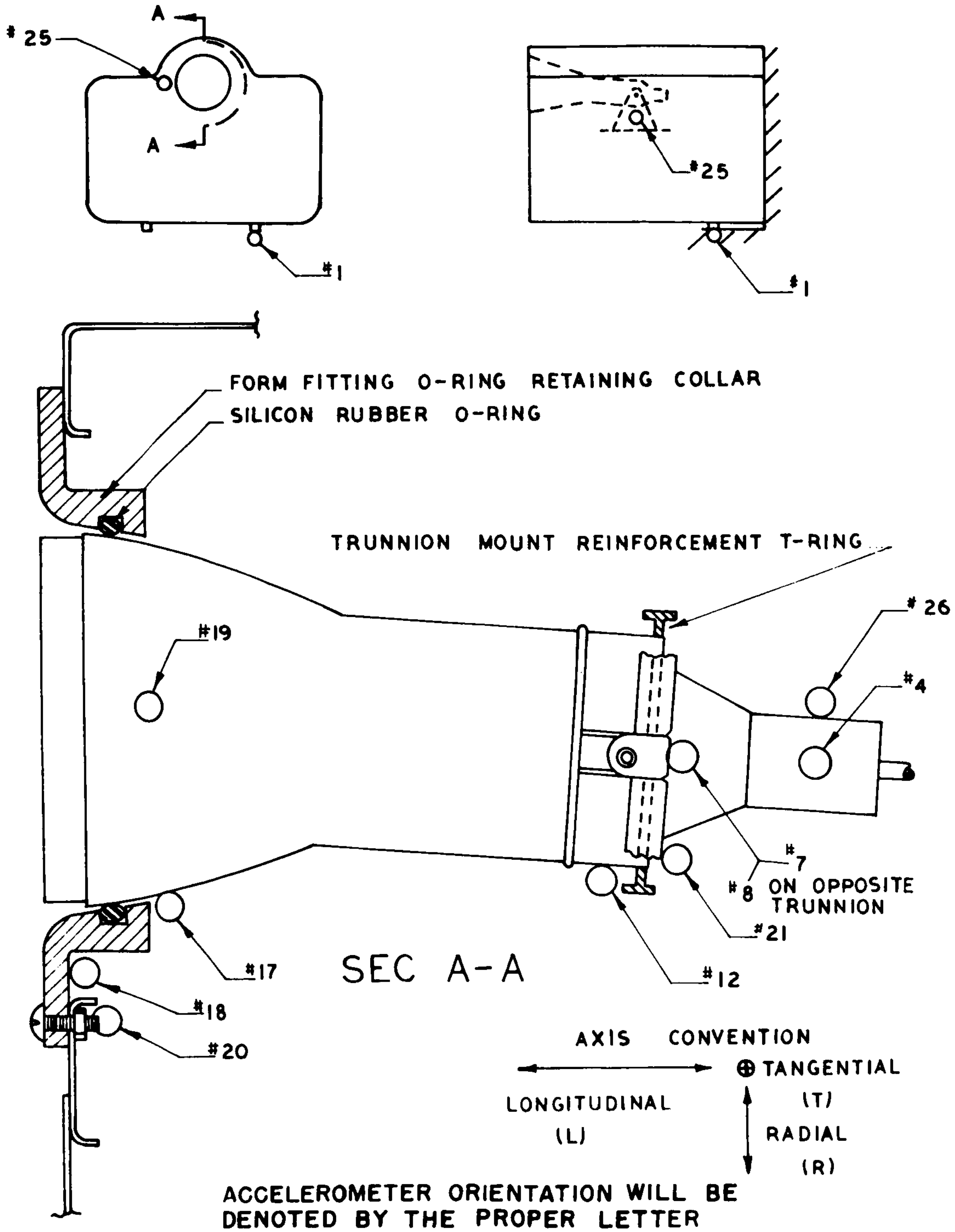


FIG 32 ACCELEROMETER LOCATIONS FOR VIBRATION TESTS 15 THROUGH 20

TABLE VIII

PRE-QUALIFICATION
SINUSOIDAL SWEEP RESONANT FREQUENCIES AND PEAK AMPLITUDES

Test No. (Axis of Vibr.)	Resonant Freq.	Peak Amplitudes (G's) for Designated Accelerometers (Refer to FIG 32 for Location and Orientation)										Remarks
		1L	18L	7L	19T	8L	24L	21L	20L	12R	17R	
15	138	6	14	13	14	15	4	16	50	16	9	TCA 2 with Rocketdyne Reinforced
(Longitudinal)	260	8	35	15	28	16	10	24	212	47	27	Trunnion Mount and Nozzle Flange
	540	7	18	16	43	29	7	7	49	11	20	
	800	10	27	22	38	18	21	20	73	20	44	
	828	11	88	-	-							
	1050	10	60	29	90	39	15	10	58	21	34	
	1920	10	70	142	260	45	30	10	72	26	152	
		1R	18L	7R	19R	8R	26R	12L	25R	12R	17R	
17	135	7	Bad	23	-	25	-	-	-	-	30	Same as above
(Radial)	165	7			25	-	64	52	45	42	-	
	270	8		24	-	22	-	-	102	-	-	
	320	8			35	-	64	27	-	43	45	
	600	9		20	24	12	22	21	41	13	49	
	780	14		56	32	53	16	18	60	18	55	
	1090	10		26	94	26	22	16	63	25	80	
	1560	10		65	65	23	18	15	42	13	160	
		1T	21T	7T	19T	8T	4T	18L	20T	12R	17R	
19	80	6	38	39	-	38	38	10	53	7	11	Same as above
(Tangential)	290	9	26	33	-	32	41	18	22	26	20	
	400	9	-	-	-	-	-	-	39	-	17	
	440	9	30	34	-	31	58	11	-	5	-	
	960	11	96	35	105	65	52	97	75	26	80	
	1450	11	25	100	65	175	11	30	95	20	64	
	1790	11	10	35	75	130	15	11	24	6	39	



ACCELEROMETER ORIENTATION WILL BE DENOTED BY THE PROPER LETTER AFTER THE LOCATION NUMBER ON THE FOLLOWING DATA SHEETS

FIG 33 ACCELEROMETER LOCATIONS FOR VIBRATION TESTS 21 THROUGH 26

TABLE IX

QUALIFICATION
SINUSOIDAL SWEEP RESONANT FREQUENCIES AND PEAK AMPLITUDES

Peak Amplitudes (G's) for Designated Accelerometers (Refer to FIG 33 for Location and Orientation)

Test No. (Axis of Vibr.)	Resonant Freq.	1L	18L	7L	19T	8L	4L	21L	20L	12R	17R	Remarks
21 (Longitudinal)	75	9	50	14	75	21	50	15	34	11	16	TCA 2 - With O-Ring Nozzle Support and Rocketdyne Trunnion Reinforcement. This engine had previously completed the vibration series with the Rocketdyne Nozzle Flange Reinforcement (Runs 15 through 20).
	290	9	80	32	90	45	70	35	-	50	50	
	440	7	16	26	44	26	52	9	-	9	25	
	1230	7	7	17	43	24	15	8	-	5	13	
		1R	18L	7R	19T	8R	26R	21R	25R	12R	17R	
23 (Radial)	125	10	10	37	-	35	37	12	34	33	37	Same as above
	290	15	34	34	-	31	60	48	65	54	85	
	640	11	8	20	-	18	11	6	45	7	19	
	890	10	50	22	-	26	10	8	100	6	35	
		1T	18L	7T	19T	8T	4T	21T	20T	12R	17R	
25 (Tangential)	155	5	7	25	-	24	35	22	24	22	7	Same as above
	300	9	35	29	-	41	29	50	110	40	115	
	570	10	35	25	-	30	15	19	57	15	43	
	740	10	38	28	-	29	16	11	40	16	45	
	1030	12	58	48	-	29	18	6	70	15	35	
	1820	13	12	86	-	220	27	15	95	25	120	

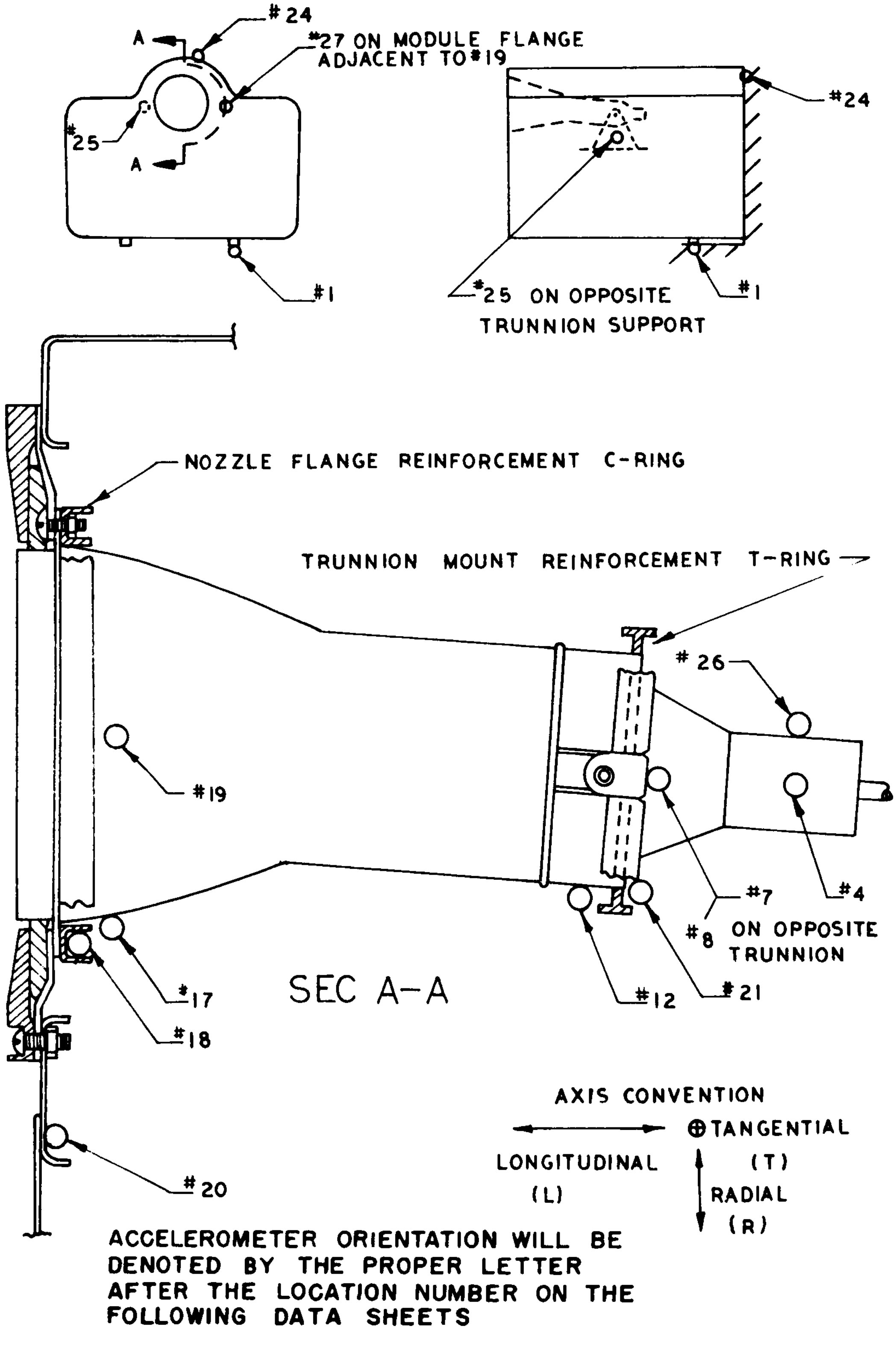


FIG 34 ACCELEROMETER LOCATIONS FOR VIBRATION TESTS 27 THROUGH 32

TABLE X

OFFICIAL QUALIFICATION
SINUSOIDAL SWEEP RESONANT FREQUENCIES AND PEAK AMPLITUDES

Peak Amplitudes (G's) for Designated Accelerometers
(Refer to FIG 34 for Location and Orientation)

Test No. (Axis of Vibr.)	Resonant Freq.	1L	20R	7L	19T	8L	27T	18L	25L	20L	17R	Remarks
27 (Longitudinal)	131	6	22	14	10	16	10	18	8	35	15	TCA 4 - Official qualification chamber modified with Rocketdyne Trunnion and Nozzle Flange Reinforcements
	152	5	9	19	10	24	4	26	9	31	7	
	201	5	27	6	17	7	11	11	8	31	15	
	215	6	29	28	21	15	21	12	16	30	15	
	259	8	208	28	112	22	62	46	24	188	48	
	346	10	49	15	30	21	31	14	18	26	33	
	522	8	67	26	75	27	61	16	36	85	36	
	749	12	18	23	57	29	54	20	28	58	60	
	845	10	62	29	90	36	100	54	25	64	65	
	1010	10	58	21	39	39	21	38	47	59	54	
	1171	10	45	22	47	35	12	9	20	54	17	
	1283	10	43	23	-	-	-	-	-	-	-	
	1320	10	-	-	97	18	27	14	43	24	18	
	1534	8	29	40	114	58	92	44	62	52	79	
	1779	10	20	93	99	109	145	35	180	26	96	
	1889	8	16	28	116	16	24	17	32	32	60	
		1R	20R	7R	19T	8R	27T	18L	25R	20L	17R	
29 (Radial)	120	8	32	23	-	23	17	18	19	48	29	Same as above
	165	8	29	20	-	28	25	36	21	78	20	
	300	9	70	20	12	35	90	36	21	160	38	
	600	10	70	-	-	-	-	-	-	-	60	
	775	9	-	70	-	78	115	30	38	103	-	
	1525	11	70	32	21	29	130	25	45	145	92	
		1T	20T	7T	19T	8T	27T	18L	25T	20L	17R	
31 (Tangential)	78	8	60	46	68	45	72	17	39	31	19	Same as above
	245	9	-	-	-	-	-	-	-	43	-	
	275	9	28	40	47	36	40	12	33	-	15	
	390	11	36	33	77	37	52	30	20	20	40	
	1010	10	21	41	40	39	50	30	38	52	30	
	1250	10	48	50	80	65	150	48	40	58	40	
	1425	10	40	88	98	75	185	42	41	37	83	
	1750	8	34	78	125	94	64	22	13	13	24	

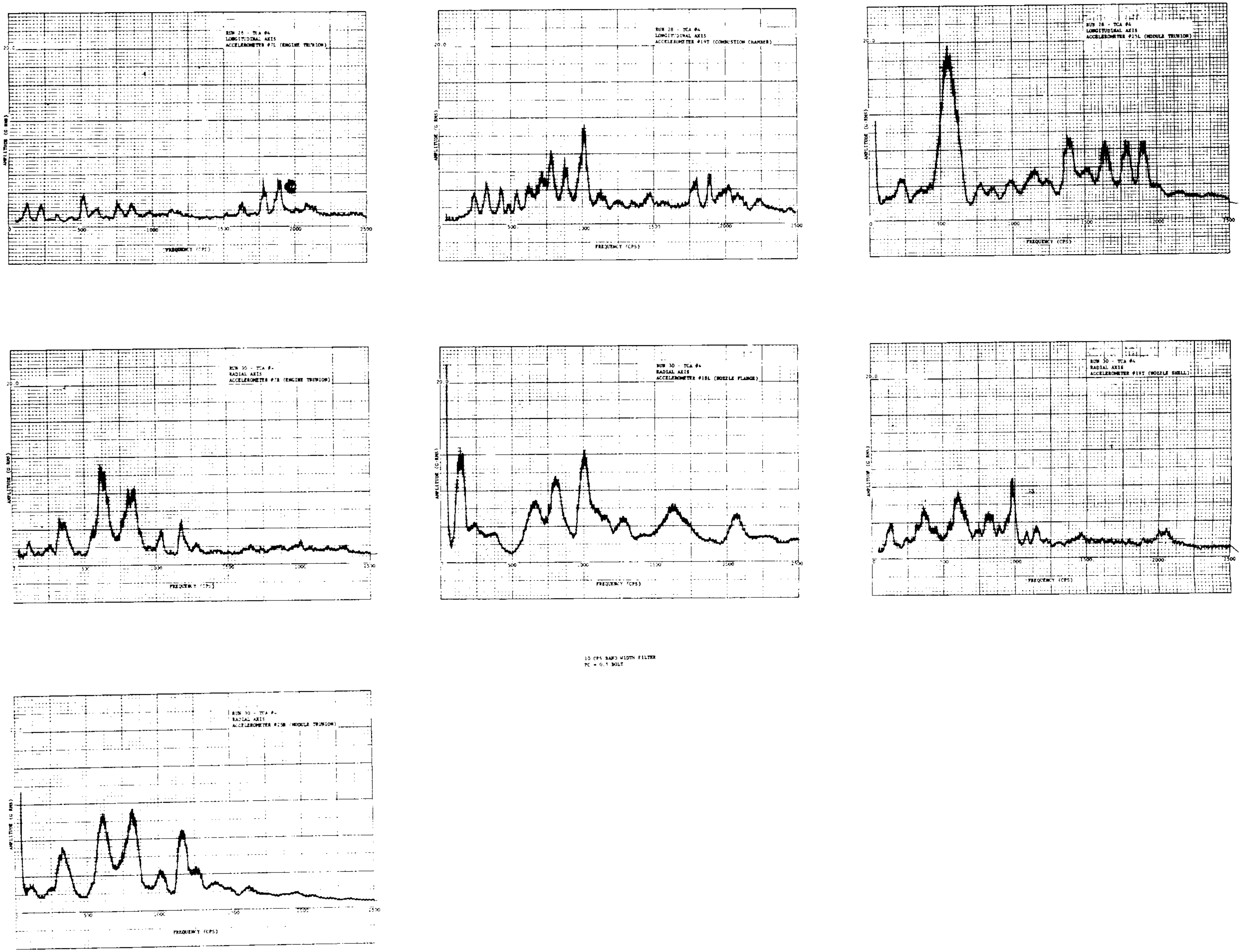
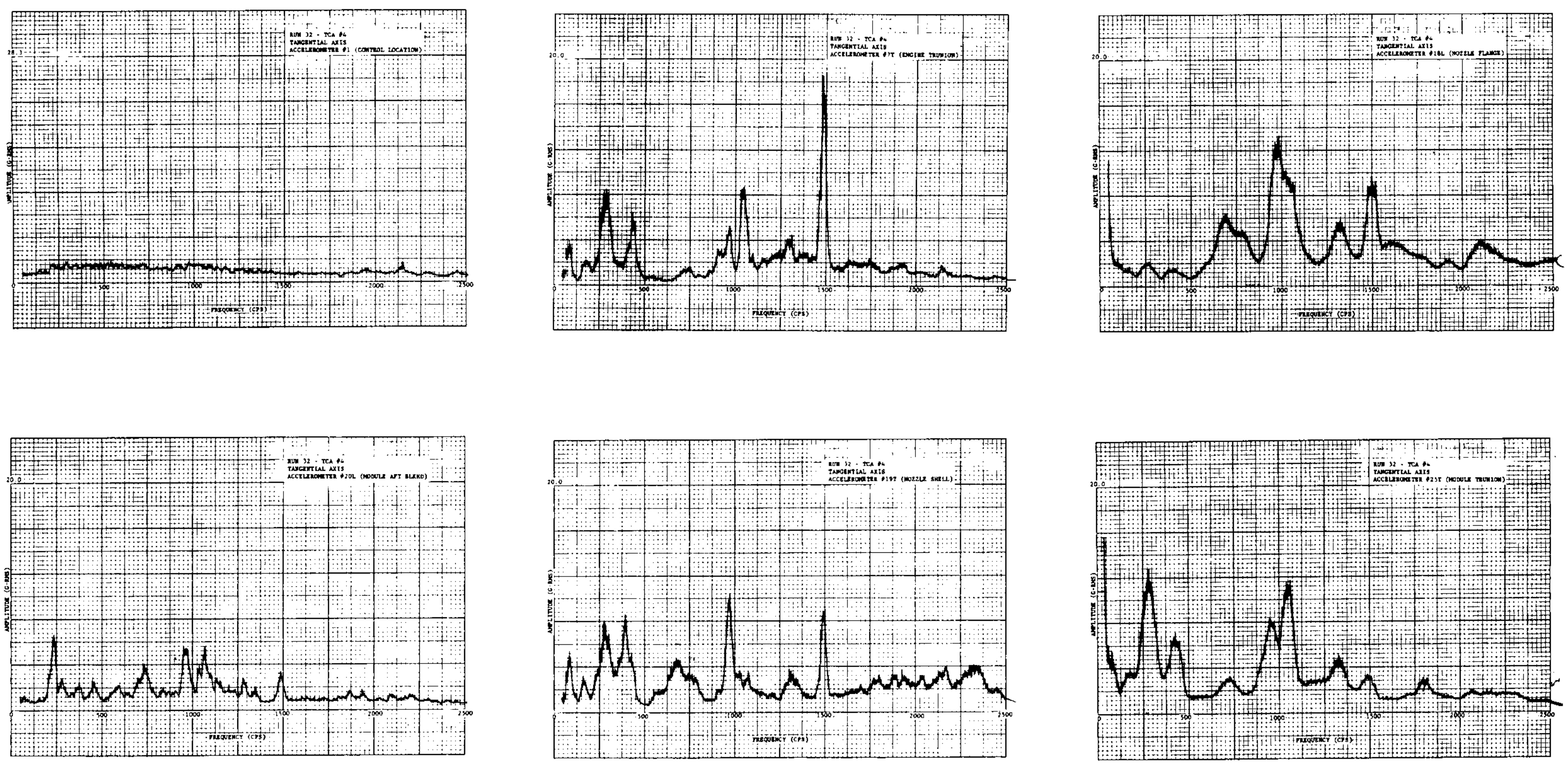


FIG 35 POWER SPECTRAL DENSITY (PSD) ANALYSIS OF RANDOM VIBRATION DATA; TESTS 28 AND 30



10 CPS BAND WIDTH FILTER
FC = 0.5 VOLT

FIG 36 POWER SPECTRAL DENSITY (PSD) ANALYSIS OF RANDOM VIBRATION DATA; TEST 32

TABLE XI

COMPARISON OF PEAK G-LEVELS FROM ALL SINE SWEEP TESTING
IN LONGITUDINAL AXIS

(1) Accelerometer (Location)	(2) TCA	Test No.	Correlatable Frequencies (cps) 150	260	525	760	1070	1890
No. 1L (Control)	3	7	6	7	10	11	11	
	1	9	6	10	10	9	11	
	3 R	13A	5	7	12	9	13	12
	3 R	13B	9	12	18	20	28	16
	2 M	15	6	8	7	10	10	10
	2 MO	25	5	9	10	10	12	13
	4	27	5	8	8	12	10	8
(No. 7L + No. 8L)/2 (Trunnion) Average	3	7	21	18	20	30	36	
	1	9	18	31	27	16	37	
	3 R	13A	24	30	36	30	72	110
	3 R	13B	30	19	32	42	36	98
	2 M	15	14	16	23	20	34	94
	2 MO	25	25	35	28	29	39	153
	4	27	22	25	27	26	30	22
No. 20L (Module Aft Bulkhead)	3 R	13A	45	83	82	58	48	90
	2 M	15	50	212	49	73	58	72
	4	17	31	188	85	64	59	32
No. 18L (Nozzle Flange)	3 R	13A	20	40	52	48	58	104
	2 M	15	14	38	18	88	60	70
	4	27	26	46	16	54	38	17
No. 17R (Nozzle Radial Response)	3 R	13A	17	38	40	49	104	116
	3 R	13B	3	23	32	95	67	100
	2 M	15	9	27	20	44	34	152
	4	27	15	48	36	65	54	60
No. 20R (Module Aft Blk. (Radial Res.)	3 R	13B	5	11	35	39	22	48
	4	27	9	208	67	62	58	16
No. 19 (Nozzle Tangent. Response)	3 R	13A	10	27	44	26	72	278
	3 R	13B	6	27	43	56	68	180
	2 M	15	14	28	43	38	90	260
	4	27	10	112	75	90	39	116
No. 27 (Module Aft Blk. Tang. Response)	3 R	13B	6	10	49	48	60	36
	4	27	4	62	61	100	21	140

1) Refer to Fig. 34 for location illustration.
2) R - indicates repaired chamber after previous vibration failure.
   M - indicates modification to basic engine.
   MO - indicates O-Ring nozzle support modification.

TABLE XII

COMPARISON OF PEAK G-LEVELS FROM ALL SINE SWEEP TESTING IN TANGENTIAL AXIS

(1) Accelerometer (Location)	(2) TCA	Test No.	Correlatable Frequencies (cps) 78	275	400	1000	1250	1425	1750
No. 1T (Control)	Mass Model	1	10	11	12	12	12		
	3	3	6	7	9	10	12	9	10
	2 M	19	6	9	9	11		11	11
	2 MO	21	9	9	7		7		
	4	31	8	9	11	10	10	10	8
(No. 7T + No. 8T)/2 (Trunnion Average)	Mass Model	1	45	27	37	43	50		
	3	3	34	23	23	53	32	45	47
	2 M	19	39	33	33	50		138	83
	2 MO	21	18	39	26		21		
	4	31	46	38	35	40	58	82	86
No. 19T (Nozzle Tangential Response)	3	3	50	18	22	100	80	60	60
	2 M	19				105		65	75
	2 MO	21	75	90	44		43		
	4	31	68	47	77	40	80	98	125
No. 18L (Nozzle Flange)	2 M	19	10	18	11	97		30	11
	4	31	17	12	30	30	48	42	22
No. 17R (Nozzle Radial Response)	2 M	19	53	22	39	75		95	24
	4	31	19	15	40	30	40	83	24

1) Refer to Fig. 34 for location illustration.
2) R - indicates repaired chamber after previous vibration failure.
M - indicates modification to basic engine.
MO - indicates O-Ring nozzle support modification.

TABLE XIII

COMPARISON OF PEAK G-LEVELS FROM ALL SINE SWEEP TESTING IN RADIAL AXIS

(1) Accelerometer (Location)	(2) TCA	Test No.	Correlatable Frequencies (cps) 120	300	600	775	1525
No. 1	3	5	6	11		10	
(Control)	1 R	11	9	10	9	10	
	2 M	17	7	8	9	14	10
	2 MO	23	10	15	11	10	
	4	29	8	9	10	9	11
$\frac{\text{No. 7 + No. 8}}{2}$	3	5	21	25		45	
(Trunnion	1 R	11	24	35	10	55	
Average)	2 M	17	25	23	16	54	
	2 MO	23	36	33	19	24	
	4	29	23	28		74	31
No. 19	2 M	17	25	35	24	32	65
(Nozzle Tangent. Response)	4	29					21
No. 17	2 M	17	30	45	49	55	160
(Nozzle Radial Response)	4	29	29	38	60		92
No. 25	2 M	17	45	102	41	60	42
(Module Trunnion Bracket)	4	29	19	21		38	45

1) Refer to Fig. 34 for location illustration.
2) R - indicates repaired chamber after previous vibration failure.
M - indicates modified basic engine.
MO - indicates O-Ring nozzle support modification.

February 24, 1966 APPROVAL TMX-53400

QUALIFICATION OF THE GEMINI SE-7 ENGINE
AS THE SATURN S-IVB STAGE
ULLAGE CONTROL THRUSTER

By Donald E. Pryor

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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